Environmental Indicators

For National State of the Environment Reporting

estuaries and the sea

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 61 environmental indicators for estuaries and the sea is recommended for Australian state of the environment reporting at the national scale. Of these, 3 relate to cited species or taxa, 9 to habitat extent, 17 to habitat quality, 6 to renewable products, 2 to non-renewable resources, 5 to water or sediment quality, 17 to integrated management, and 2 to ecosystem-level processes. 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 estuaries and the sea.

Aims of the study

- present a key set of environmental indicators for estuaries and the sea 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 the 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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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 (SoE) reporting at the national level to enhance the quality, accessibility and relevance of data relating to ecologically sustainable development.

The broad objectives of state of the 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 judgements 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 Commonwealth of Australia 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 estuaries and the sea chapter of *Australia: State of the Environment 1996,* the pressures on estuaries and the sea were presented in detail, together with an account of the current condition of the marine and estuarine environment, and some responses to those pressures. In the present report, indicators of state or condition are routinely called "condition indicators".

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 commitments 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 developing the state of the environment reporting system. Environmental indicators for the seven SoE themes were developed in parallel, with close consultation between the themes.

Environmental indicators

Environmental indicators have been defined as:

> *... 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 interpretative framework and has meaning beyond the measure it represents* (Commonwealth of Australia 1996a).

The monitoring program for an indicator comprises repeated measurements of the variable in various places and times, and in a defined way. Comparison of this set of repeated measurements with a benchmark set or condition provides the basis for detecting change. Over time, in the case of a Condition indicator, this change can be matched to particular Pressure indicators and Response indicators to assess both the nature of the effects of particular Pressures and the efficacy of our management responses to key environmental issues. The scale at which the information is needed for management purposes dictates the scales — spatial and temporal — at which the monitoring program must resolve changes in each indicator.

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 estuarine and marine 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 Commonwealth of Australia 1994); the set of key indicators should meet as many of these criteria 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 important 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.

Conceptual and policy approaches to estuaries and the sea

At present there is no broad Commonwealth, State or Territory legislation for the integrated conservation and management of estuarine and marine ecosystems. Each jurisdiction covers appropriate sectors of activity with sector-specific legislation. In June 1993, Australia ratified the international *Convention on Biological Diversity,* which was one of the outcomes of the Earth Summit held in Rio de Janeiro in June 1992. The objectives of this Convention are:

> *The conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.*

The aims of this Convention have been incorporated into the *National Strategy for the Conservation of Australia's Biological Diversity* (Commonwealth of Australia 1996b), which has been endorsed by the Commonwealth Government and all State and Territory Governments. The goal of this Strategy is to protect biological diversity and maintain ecological processes and systems. The Strategy aims to provide the link between current activities and the effective identification, conservation and management of Australia's biological diversity. The *National Stategy for the Convention of Australia's Biological Diversity* is closely linked to the *National Strategy for Ecologically Sustainable Development* (Council of Australian Governments 1992). Implementation of the *National Strategy for the Conservation of Australia's Biological Diversity* will require actions that affect virtually all of Australia's terrestrial, aquatic and marine ecosystems. Most ecosystems will continue to be subject to a multiplicity of uses, many of which depend on the maintenance of, or are impacting on, biological diversity.

Achieving ecologically sustainable development requires all resource sectors to conduct their activities in the estuarine and marine environments in an ecologically sustainable manner. To assess the ecological sustainability of human activities, information is required on the way in which the natural ecosystems respond to, or perform, in the face of the various pressures imposed on them. The ESD principles suggest that, in response to evidence of adverse impacts, the resource-sector activities would need to be adapted in ways that will ensure the sustained and healthy persistence of the ecosystems. To be effective, this evidence will need to be based on ecosystem-level knowledge of adverse effects because cause–effect models that underlie most human activities in marine and estuarine ecosystems are poorly developed and highly uncertain. Hence these ecosystems cannot be managed *only* on information about human activities and pressures.

Focusing on elements and the integrity of the ecosystem as the explicit management end points ensures that ESD is implemented in a manner that uses and responds to holistic ecosystem performance rather than being constrained to individual sector-based activities, impacts or remedial measures. In this way, interactions between various resource sectors — in terms of their effects on ecosystems — may be integrated into ESD. This approach also ensures that ESD assessments focus on important (and valued) ecosystem management end points, not on intermediate activities or effects that are of minor significance for ecosystem integrity.

At present, the oceans and estuaries are subjected to multiple uses, operating within many jurisdictions and within multiple forms of management. Australia is now proceeding to develop an overarching Oceans Policy, which will provide "an integrated and strategic platform for the better planning and management of our oceans" (Australia's Oceans New Horizons, Commonwealth of Australia 1997). This new platform will encourage an integrated approach to managing the multiple users of the ocean resources, consistent with Australia's domestic and international responsibilities in conserving and managing the ocean's ecosystems. To achieve this, the oceans and estuaries will need to be managed in an integrated manner within an ecosystem-management framework.

Integrated ecosystem management

Basing management of ocean and estuarine ecosystems on integrated ecosystem management principles is a widely adopted goal (see for example Sherman 1994). The National Strategy for the Conservation of Australia's Biological Diversity develops the need for integration of management in a number of its objectives, including:

> Objective 1.3 "Improve the standards of management and protection of Australia's biological diversity by encouraging the implementation of integrated management techniques"; and
>
> Objective 2.1 "Develop and implement national integrated policies for the ecologically sustainable use of biological resources".

The principles underlying ecosystem management are perhaps best conceptualised in the emerging working definition: "Ecosystem management integrates scientific knowledge of ecological relationships within a complex socio-political and values framework toward the general goal of protecting native ecosystem integrity over the long term" (Grumbine 1994). The goals of ecosystem management may be summarised (after Grumbine 1994) as being to:

- maintain viable populations of all native species i*n situ;*
- represent, within protected and managed areas, all native ecosystem types across their natural range of variation;
- maintain evolutionary and ecological processes;
- manage over periods of time long enough to maintain the evolutionary potential of species and ecosystems; and
- accommodate human use within the above constraints.

Ecosystem management also has a number of important functional attributes (after Grumbine 1994). It

- operates across the complete hierarchical context of biological diversity (genes to ecosystems) in an attempt to maintain a "systems" perspective;
- operates within ecological boundaries at a variety of natural scales, and as needed across geopolitical boundaries and scales;
- has as its major target the concept of maintaining ecological integrity — managing to maintain natural genes, species populations, habitats and ecosystems, and the ecological patterns and processes that maintain this diversity;
- is based on monitoring appropriate indicators to provide feedback on ecosystem structure and function in response to management settings;
- is adaptive;
- promotes inter-agency cooperation, organisational change, and capture of improved data and knowledge about ecosystems;
- promotes the concept of human uses in harmony with managed ecosystems; and
- recognises that human values play a dominant role in establishing ecosystem management goals.

Adoption of an ecosystem-management framework implies the need for "a reasonable understanding of the physical and chemical environment and the biological species which describe an ecosystem plus an understanding of the interactions among and between the species complex as well as their environment." (Harden Jones 1994). However, in Australia (as elsewhere) the goals and objectives of integrated ecosystem management have not been well formulated into integrated marine management frameworks or into marine management policies, plans, strategies and actions. In interpreting the ecosystem-management principles and framework for the purpose of monitoring and reporting on ecosystem condition ("health"), five key attributes of marine ecosystems have been conceptualised into an operational framework. They are diversity, stability, yields, productivity and resilience (Sherman 1994). These central ecosystem attributes can be used to guide the development of environmental indicators for the purpose of assessing the condition of ecosystems and their components and processes, and to assess the success of the integrated management framework. We have "operationalised" the ecosystem management principles in selecting appropriate State (Condition), Pressure and Response indicators by ensuring that each key indicator represents, or relates directly to, one or more of the five key ecosystem attributes described above.

Individual indicators may be linked to more than one of the key ecosystem attributes, and in practice each key ecosystem attribute can be represented by various structural elements and functional processes in ecosystems. The biological aspects of the structural diversity of ecosystems can be classified hierarchically into a series of levels ranging from the molecular to the ecosystem level. Levels in this structure include: genotypes, species, populations, assemblages and ecosystems. The variety of biological configurations at all levels is extremely large, currently unknown and probably unmeasurable. So, for monitoring and reporting on the diversity of biological systems, surrogates need to be chosen to represent the key elements at each level of diversity in our estuarine and marine ecosystems. For functional ecosystem processes, the indicators have been chosen to ensure that they represent important aspects of the ecosystem attributes, and that potential changes — evaluated against established baseline or benchmark conditions (including natural dynamics) — can adequately represent change of the broader biological elements in the ecosystems and important processes.

While it may be possible to argue that ecosystem-level surrogates can be used to represent the whole suite of levels of ecosystem attributes, this is far from proven or practical. For example, environmental domains (major habitats) are commonly adopted at the national scale because they are available at a consistent level of detail. This high level of organisation tends to integrate ecological processes and functions such as nutrient and energy cycling, which are also components of biological diversity.

However, the extent to which environmental domains comprehensively represent the other aspects of diversity remains to be fully assessed. So surrogates need to be chosen for the elements in each important level of our perceived hierarchical classification of the living components of ecosystems and processes. These surrogates (the indicators) need to be important elements of the ecosystems and representative of levels from whence they are drawn; even given various measurement difficulties (see below), imprecise measures on important attributes will generally be more useful for state of the environment reporting purposes than accurate, precise and powerful measures of minor aspects of an ecosystem. (This is pseudo-power; see Ward and Jacoby 1995). Other decisions on the nature and level of surrogacy depend on the scale of measurement and reporting and the resources available. The levels of precision and accuracy required in the measurement program for any particular indicator need to be matched to the reporting needs for that indicator. Once these levels are achieved in a measurement program, further detail is redundant.

Considerable debate exists (see for example King 1993) about the nature of ecosystems — in summary, strictly hierarchical versus purpose-defined, dynamic, process-based boundaries. Here we adopt a neo-classical approach. This assumes that ecosystems have spatial and temporal scales in structure and processes that are larger than those of component species, populations, assemblages and associated processes such as recruitment and production.

We base our approach to indicator selection on equivalent initial weighting of surrogates for the key ecosystem attributes. This avoids a bias that is well demonstrated in the scientific literature, but not well supported by critical analysis. Structural aspects of ecosystems are crucial, but the dominance of diversity indices analysis has biased approaches to development of ecosystem indicators of diversity in the past. Ecosystem functions and processes have dominated resource-sector (fisheries) analyses, since it is typically production (biomass) that is the main target (end point) for fisheries management. We try to take a balanced approach, considering both structural and functional attributes of ecosystems where they are consistent with the key ecosystem attributes. Nonetheless, the key set of indicators will comprise more structural than functional indicators because of the high level of structural redundancy in marine and estuarine ecosystems, and the consequent tendency for structural indicators to be more sensitive and provide earlier warning of important environmental change.

For each of the key indicators, the accuracy and precision required in measurement programs will need to be determined in detailed assessments, and then compared with those currently available from existing monitoring, where it exists. In this way, once the indicators are defined the nature of the required measurement programs can be also defined. Comparing these with existing efforts will determine where improvements or amendments are needed, or where major gaps exist.

Spatial and temporal scales for monitoring indicators

Choosing the appropriate spatial and temporal scales for capture of data on national indicators is critical; inappropriate choices here will mean that monitoring data fail to adequately reflect ecosystem changes at scales that are meaningful for management agencies, and so indicator data will not prove useful for management of estuarine and marine ecosystems. This means that optimal choices of space and time scales for national SoE indicators will be closely coherent with the scales at which the ecosystems are managed and, to the extent possible, coherent with natural boundaries of the ecosystems.

Choices of temporal scales will be largely unique for each indicator, and be established separately for each monitoring program. This is because the various issues and elements targeted by national SoE indicators will have different natural dynamics, and a monitoring program to detect change will need to employ a temporal scale appropriate to the natural scales of change but modified according to the management needs for information on rates of change. For example, elements that change only slowly may need to be measured only infrequently in order to detect change; if a small change is of very great importance, however, they may need to be measured frequently to ensure that such changes are not occurring. Hence, even if changes are expected to be slow it is important to verify that this is the case and to provide reassurance that our expectations are correct and that unpredicted impacts are not occurring.

A central issue for SoE reporting is to be able to effectively create the linkage between local and international scale. At each sub-scale, the boundaries and complexity of the system being tracked are different. One way of dealing with this is to ensure that there is an appropriate synthesis and reporting for each indicator at each level of the spatial hierarchy. So, for example, whilst it may be very important for chlorophyll concentrations — or levels of nitrogen species dissolved in water — to be monitored in an estuary at the very finest scales of space and time (for instance, to report on improvements in sewage treatment), a compiled summary of such data reported at the estuary level will be of little value for national-scale reporting and irrelevant to international reporting needs. It may be more useful to report on the number of estuaries within classes of chlorophyll concentrations, and those exceeding regional or local criteria established to reflect improvements in sewage treatment as established using regulatory standards and implemented within the integrated catchment management framework.

Aside from appropriate scales and linkages, it will also be important to ensure that we identify processes to capture, maintain and report on the uncertainty inherent in initial data gathering, and the uncertainties introduced by any aggregation processes we may impose.

Since detection of important change is the key rationale for the existence of the SoE reporting process, it is essential that any reporting is accompanied by estimates of uncertainty for the data and information reported. Estimating the risk of falsely indicating no change when important change has in fact occurred — and of the converse, indicating change when in fact no important change has occurred — is critical to establishing and maintaining the credibility and broad acceptance of the SoE process. Managers of all resources operate on a risk-acceptance basis, and they need to know (or be able to estimate) how risky a decision or process is in terms of established objectives. National-scale reporting may introduce large errors in the data aggregation process, and estimates of both uncertainty and the risk of false positives and negatives are essential companions to any derived information used to report on national trends.

Regionalisations and spatial scales for reporting on national environmental indicators

In several States (at least Queensland, New South Wales and Victoria) the ecosystems of estuaries and coastal river catchments are being managed using various forms of Integrated Catchment Management (ICM). Although each jurisdiction uses different approaches to achieving integrated management, all appear to aspire to integrated approaches to management and conservation of the natural elements of the various ecosystems within each defined catchment area. Most ICM areas are based on the natural catchment boundaries, on part-catchments where the catchments are large, or on multiples of catchments where the catchments are small. In essence, this provides close coherence between the spatial boundaries of the management areas and the natural boundaries of the ecosystems. Where the two sets of boundaries — the natural and the management — are not coherent, the natural catchments can nonetheless be divided or aggregated in a simple manner to closely resemble the management boundaries. It is clear, therefore, that the ICM area boundaries offer a cohesive framework for ecological assessment of the coastal catchments and estuaries, and they form the optimum basic spatial unit for monitoring national-level SoE indicators in estuarine ecosystems.

In Queensland, 32 catchments have been defined that are closely related to natural drainage boundaries. The Integrated Catchment Management (ICM) process is supervised by a State-wide committee (the Queensland Catchment Management Coordinating Committee — CMCC), and is implemented in each catchment under the guidance of a catchment-scale Catchment Area Committee (CAC). ICM is implemented in Queensland by fostering voluntary changes in each catchment. The ICM process is used, through the CMCC and the local CAC, to investigate various issues in a catchment, prioritise issues, and plan, develop and promote corrective actions (Queensland Department of Primary Industries 1993). It is therefore at the catchment level that data and information on environmental indicators will be most useful. Here, changes in management practices implemented as a result of ICM can be tracked at scales in space and time that have meaning for local stakeholders, and for the natural scales upon which ecosystems operate.

For marine coastal waters, the Environmental Resources Information Network (ERIN), in conjunction with State, Territory and Commonwealth agencies, has recently completed an assessment of bioregional boundaries in inshore and coastal marine ecosystems. This produced the meso-scale Interim Marine and Coastal Regionalisation of Australia (IMCRA), which identifies 59 ecologically based spatial units (regions and subregions) surrounding the coast of Australia (IMCRA Technical Group 1997). The IMCRA regions and subregions provide an appropriate set of spatial units for use in SoE reporting for many of the key indicators proposed here. At present, the IMCRA spatial units have no relation to management systems; they are purely of biological and biophysical origins. However, these subregions represent one of the levels in the hierarchical classification of marine ecosystems that approach a useful scale for management purposes.

The 59 mainly inshore units identified around the Australian mainland and Tasmania by IMCRA (Version 3) are nested within 18 larger units representing demersal inshore provinces. Most of Australia’s offshore islands have not been included in this version of IMCRA. Regions in the remainder of the EEZ — outside the IMCRA subregions and the demersal provinces — have yet to be finalised and agreed. Nonetheless, there will probably be fewer of these other regions, and they will be broader and extend to the EEZ boundaries. For the purposes of this report, the broader regions are regarded as Marine Regions. The IMCRA subregions may be considered, for the purposes of this report, to be fully nested within relevant parts of Marine Regions that have yet to be defined and agreed.

Key Indicators For National State Of The Environment Reporting On Estuaries And The Sea

The 61 key indicators presented here (Table 1) have been derived from the following sources:

- review of relevant indicators used in other State, national and overseas state of the environment reports (including the 1996 Australian State of the Environment Report);
- suggestions for consideration by experts attending an Estuaries and the Sea Indicators workshop, held in Adelaide in 1996;
- review of the relevant scientific literature (Australian and overseas); and
- consultation with colleagues in various Commonwealth and State agencies.

The key indicators are classified into eight groups, each of which represents a class of issue or elements of the environment.

Class 1: Protected and Cited Species/Taxa

This is a group of three indicators comprising all the species explicitly protected by name under relevant Commonwealth or State/Territory legislation, or as the subject of bilateral arrangements or international agreements. These indicators are typically the subject of reporting requirements under legislation such as the Commonwealth's *Endangered Species Protection Act.*

Class 2: Habitat Extent

This group of nine indicators documents the areal extent of the major marine and estuarine habitat types, with boundaries defined largely on the grounds of technological feasibility. Although the surface area of a viable habitat type is a very crude measure of its condition, monitoring the presence or absence of a habitat type is a surrogate that is more or less achievable with current technology for most indicators.

Class 3: Habitat Quality

This group of seventeen indicators is designed to permit the integrity of the major habitats (from Class 2 above) to be assessed in a more detailed manner. Typically, these indicators rely on species- or assemblage-level information. This is the detailed, fine-scale biological information that will permit the integrity of the major habitats to be closely monitored on a national scale.

Class 4: Renewable Products

These are six indicators that document the various aspects of the nature and production of marine and estuarine living resources. In a very broad sense, the continued production of marketable marine products is related to a healthy set of ecosystems, and so production level is a useful, although crude, indicator of the condition of the marine and estuarine ecosystems from which the products are derived.

Class 5: Non-renewable Products

These two indicators document various aspects of the exploitation of minerals, oil and gas, sand and other non-living and non-renewable resources of the estuaries and the sea. These indicators are regarded as pressures on living components of estuarine and marine ecosystems.

Class 6: Water/Sediment Quality

These five indicators document the levels of contaminants in various elements of the marine and estuarine ecosystems. The contaminants are considered mainly to be pressures on living components of these ecosystems.

Class 7: Integrated Management

These seventeen indicators measure aspects of our efforts to integrate the management of estuarine and marine ecosystems in order to achieve equity — both within and between generations — in the conservation and use of living and non-living resources of the estuaries and oceans.

Class 8: Ecosystem Level Processes

These are two broad-scale indicators that are, or are related to, important functions or processes in marine and estuarine ecosystems. They are also important to the ability to interpret trends that might be detected in the other indicators.

Note that all the protected species indicators are described in detail in the Report on key Indicators of Biodiversity (Saunders *et al.* 1998).

A considerable number of potential indicators (Proto-Indicators) were considered for inclusion in the key indicators list. Such an indicator may have failed to be included in the final list for any of a number of reasons. Typically, however, biological Proto-Indicators failed to make the list because there was major uncertainty about their national significance, they overlapped with other key indicators, or there were major anticipated technical problems with detecting and evaluating change. These proto-indicators are listed in Appendix 1, with an indication of why they failed to be included as key indicators.

Table 1

Key Indicators for Estuaries and the Sea

Issue or Element	Indicator	Condition (C), Pressure (P) or Response (R)
Class 1: Cited species/taxa		
Protected species	1.1 marine species rare, endangered or threatened	R
Cited species/taxa	1.2 protected species populations	C
Cited species/taxa	1.3 seabird populations	C
Class 2: Habitat Extent		
Habitat extent	2.1 algal bed area	C
Habitat extent	2.2 beach and dune area	C
Habitat extent	2.3 coral reef area	C
Habitat extent	2.4 dune vegetation	C
Habitat extent	2.5 intertidal reef area	C
Habitat extent	2.6 intertidal sand/mudflat area	C
Habitat extent	2.7 mangrove area	C
Habitat extent	2.8 saltmarsh area	C
Habitat extent	2.9 seagrass area	C
Class 3: Habitat Quality		
Habitat quality	3.1 algal bed species	C
Habitat quality	3.2 algal blooms	P
Habitat quality	3.3 beach species	C
Habitat quality	3.4 coral reef species	C
Habitat quality	3.5 dune species	C
Habitat quality	3.6 fish populations	C
Habitat quality	3.7 intertidal reefs species	C
Habitat quality	3.8 intertidal sand/mudflat species	C
Habitat quality	3.9 islands and cays species	C
Habitat quality	3.10 mangrove species	C
Pests (exotic)	3.11 pest numbers	P
Habitat quality	3.12 saltmarsh species	C
Habitat quality	3.13 seamount species	C
Habitat quality	3.14 seagrass species	C
Pests (native)	3.15 species outbreaks	P
Habitat quality	3.16 subtidal sand/mudflat species	C
Habitat quality	3.17 chlorophyll concentrations	C

Class 4: Renewable Products			
Aquaculture	4.1	aquaculture effort	P
Aquaculture	4.2	aquaculture production	C
Seafood	4.3	fish stocks	C
Seafood quality	4.4	seafood quality (contamination)	C
Effects of fishing	4.5	trawl fishing area	P
Effects of fishing	4.6	fishing gear	P
Class 5: Non-renewable Products			
Mining	5.1	ocean exploration	P
Mining	5.2	ocean mining	P
Class 6: Water/Sediment Quality			
Sediment quality	6.1	sediment quality (contaminants)	P
Water quality	6.2	sentinel accumulator program	P
Water quality	6.3	turbidity	P
Water quality	6.4	water nutrients (nitrogen)	P
Water quality	6.5	seabird eggs (contamination)	P
Class 7: Integrated Management			
Integrated management	7.1	beach stabilisation	R
Integrated management	7.2	catchment development	P
Integrated management	7.3	catchment management programs	R
Integrated management	7.4	coastal care community groups	R
Integrated management	7.5	coastal discharges	P
Integrated management	7.6	coastal population	P
Integrated management	7.7	coastal tourism	P
Integrated management	7.8	fishing effects on non-target biodiversity	R
Integrated management	7.9	Great Barrier Reef management	R
Integrated management	7.10	integration of management	R
Integrated management	7.11	marine network participation	R
Integrated management	7.12	marine protected areas	R
Integrated management	7.13	Commonwealth Government marine management	R
Integrated management	7.14	ship visits	P
Integrated management	7.15	shipping accidents	P
Integrated management	7.16	State Government marine management	R
Integrated management	7.17	World Heritage Area tourism	P
Class 8: Ecosystem-level Processes			
Ecosystem process	8.1	sea level	C
Ecosystem process	8.2	sea surface temperature variability	C

Class 1: Protected and Cited Species/Taxa

This group of indicators comprises all the species and other identified taxa explicitly protected by name under any relevant Commonwealth or State/Territory legislation. They are typically the subject of reporting requirements under legislation such as the Commonwealth's Endangered Species Protection Act or related Acts in the States and Territories, or under Commonwealth commitments to external agreements such as the Convention on International Trade in Endangered Species (CITES).

Indicator 1.1 Marine species rare, endangered or threatened

This indicator — covering marine mammals, reptiles, birds, fish, invertebrates and plants (including relevant species of seagrasses or algae) — is the number of named species or similar-level taxa in each of the relevant IUCN (World Conservation Union) categories and the subject of State, Territory or Commonwealth legislation.

The indicator is being developed as part of the Biodiversity theme; for details, refer to Saunders, *et al*, 1998.

The species/taxa to be included under this indicator will change as the various jurisdictions gather better information about the species and taxa of concern. The main species and taxa to be covered are:

- marine mammals — whales; dolphins and porpoises; seals; dugong.
- birds — penguins; albatrosses.
- reptiles — sea snakes; turtles; crocodiles.
- fish.
- invertebrates.
- plants — vascular; algae.

Indicator 1.2 Protected species populations

This indicator covers populations of each species of the marine mammals, reptiles, birds, fish, invertebrates and plants covered in Indicator 1.1. It also is being developed as part of the Biodiversity theme.

Indicator 1.3 Seabird populations

This indicator covers populations of seabirds and shorebirds, particularly migratory seabirds that are the subject of various international and bilateral conventions and agreements. Like Indicators 1.1 and 1.2, it is being developed as part of the Biodiversity theme; for details, refer to Saunders, *et al,* 1998

Class 2: Habitat Extent

This group of indicators documents the areal extent of the major marine and estuarine habitat types, with boundaries defined largely on the grounds of technological feasibility. Although the surface area of a viable habitat type is a very crude measure of its condition, monitoring the presence or absence of a habitat type is a surrogate that is more or less achievable with current technology for most indicators. Generally speaking, the extent of habitats within each spatial unit will be measured using existing remote sensing technologies or those under development.

In this context, habitat refers to the place, or type of site, where an organism or population occurs naturally (UN *Convention on Biological Diversity 1992.* Therefore, for the purposes of SoE reporting only habitats that exist naturally *in situ* are considered to be habitat. Remediated and artificially maintained marine and estuarine habitats that are located outside their normal conditions of occurrence — for example, in deeper or shallower waters, or in artificially created wetlands or channels — may not achieve the objectives of the UN Convention, *the National Strategy for Ecologically Sustainable Development* or the *National Strategy for the Conservation of Australia's Biological Diversity,* and so cannot be considered to be natural habitat in the context of SoE reporting.

Indicator 2.1 Algal bed area

Description

This indicator is an estimate of the area (km^2) of macro-algal beds, assemblages and their cover on hard and soft substrata in subtidal waters in estuaries, on the coastal fringes of the mainland and on the offshore islands and dependencies.

Rationale

Subtidal beds of macroalgae are important elements of shallow waters (<50 m depth) in estuaries, bays and coastal regions. Whilst they are mainly concentrated in temperate zones of Australia, where there are high levels of endemicity, some taxa (such as *Halimeda*) are also important in the tropics. The distribution of many other tropical genera is highly uncertain. Apart from their intrinsic floral values as a diverse suite of species, algal beds have important ecological roles in shallow marine systems. They harbour many species of fauna valued for commercial and recreational purposes, and are important primary producers in a number of near-shore environments. Algae are generally sensitive to water quality — particularly to turbidity, but also to nutrients and some chemical residues. In temperate areas, algal beds are threatened by invasive pest species (some of which are algae) and by long-term changes in environmental conditions such as sea level and climate changes that result in increased runoff of sediments from land and other threats.

Analysis and interpretation

Estimates of the area covered by individual assemblage types should be part of the analysis of the survey data. Surveys of algal beds have been conducted in Tasmania, Victoria and South Australia. Errors in the mapping and survey process should be estimated (or measured) and tracked throughout an aggregation process across individual patches of assemblages. The extent of change in either the overall area of beds, or in individual assemblages, that is important is unknown and a precautionary approach would be to adopt the position that any detectable change is adverse. No estimates are available of the power of any of the routine survey programs to detect change. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

The subtidal algal beds should be monitored using a combination of remote sensing tools and ground-truthing based on diver and video surveys. The most appropriate mix of remote sensing tools can be determined only by pilot studies at a range of relevant spatial and temporal scales, and across the relevant national scale of distribution of algal beds.

Algal beds may change quickly in response to disturbances, and they should be assessed annually in areas where threats/pressures are suspected to be adversely influencing them. In areas where threats are less important or suspected, they should be assessed every 4-5 years.

The assemblages and area of cover should be mapped to within 10 to 100 m of true position. This is readily achievable with modern positioning and navigational equipment

Reporting scale

The areal extent (km^2) of each assemblage type should be summarised and recorded for each estuary and IMCRA subregion in tabular form. This should then be aggregated to Marine Regions, and subsequently nationally in additional tables. The extent of each assemblage should be recorded for each subregion, together with an estimate of uncertainty (say 95% confidence limits). The difference between this estimate and any previous (or baseline) estimate should then be expressed as an estimate of change. An estimate of the size of change that could be statistically detected with the methods used should also be recorded.

Outputs

The outputs should be presented in the form of maps annotated with tables of areas by subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Special-purpose studies have been undertaken in Victoria, Tasmania and South Australia, and CSIRO is conducting a coarse scale (1:100 000) national assessment of algal bed distribution. This work has created a data baseline. However, most studies have been carried out using different methods, and intercomparisons would be difficult. The State agencies involved are those responsible for environment and conservation and fisheries management.

Linkages to other indicators

This indicator is closely linked to the quality of algal beds, and may be mapped as part of the comparable indicator for seagrasses. Algal beds are sensitive to many of the same pressures as seagrass beds, including nutrient and turbidity stresses. This indicator is also related to Biodiversity Indicators 11.1 and 11.2.

Indicator 2.2 Beach and dune area

Description

This indicator is an estimate of the area (km²) of unstable and unvegetated dunes and beaches (the mobile sand) on the coastal fringes of the mainland and on the offshore islands and dependencies.

Rationale

Australia is world famous for its beaches. Holidays at the beach feature highly in all aspects of Australian lifestyle and culture. Cities and towns are located near beaches because of their scenic and recreational attractions. However, in many places these same beaches are eroding, resulting in considerable remediation efforts. In some areas mobile dunes also threaten to move inland, affecting property, property values, native vegetation and transport corridors. Some of these changes can be ascribed to the effects of natural climatic shifts, while other are related to human action such as the degradation of dune vegetation. Predictions of dune stability are a key aspect of coastal planning.

Analysis and interpretation

Estimates of the area covered by beaches and unstable dunes can be interpreted in relation to sand supply for local beaches, and as a key parameter for predictions about future sand movements. Beaches and dunes are dynamic, and target estimates for minimum acceptable change are probably not appropriate. Monitoring and reporting of the magnitude and direction of changes is, however, important for local planning purposes. The level of important change will be evaluated by assessment of the time-series of monitoring data and an assessment of the trajectory of changes.

Monitoring design and strategies

The area (km²) of beaches and unvegetated dunes can be readily estimated from remote sensing data. Area estimates from images (air photos and/or satellite images) at 1:25 000 scale across all dunes and beaches will track changes at the appropriate scale. This work involves photogrammetric analysis of aerial photography, aircraft scanner data or satellite images to determine the area of Holocene dunes and of recent/contemporary unstable dunes and beaches.

Change in dune and beach area should be reported on a 4-5 year cycle, but the frequency of sampling measurements will need to be developed as part of a detailed sampling approach. Key issues will be the extent of natural (seasonal) variability and detecting long-term change above the "noise" of natural variability.

The spatial accuracy and resolution will need to be determined by a pilot study designed to evaluate change detection capability and to determine the statistical power of any proposed routine monitoring program.

Reporting scale

The areal extent (km²) of unvegetated sand cover should be summarised and recorded for each estuary, beach and IMCRA subregion in tabular form. This should then be aggregated to Marine Regions, and subsequently nationally in additional tables. The extent of unvegetated sand for each IMCRA subregion should be recorded with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps, annotated with tables of areas (km²), showing beaches and estuaries by IMCRA subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Special-purpose studies have been undertaken in most States and have created a baseline of historic data. Most, however, have been carried out using different methods, and intercomparisons would be difficult. The agencies involved are those in each State responsible for environment and conservation, coastal management, and local government.

Linkages to other indicators

Beaches and dunes may be mapped as part of the remote sensing of coastal vegetation. The changes in beach and dune extent are closely related to those in dune vegetation, and these two indicators should be closely linked. Sand area may also be closely linked to the spread of urban areas, and to changes in climate. This indicator is also related to Biodiversity Indicators 11.1 and 11.2.

Indicator 2.3 Coral reef area

Description

This indicator is an estimate of the number and area of coral reefs of various types on the coastal fringes of the mainland and on the offshore islands and dependencies.

Rationale

Coral reefs are a very high profile marine habitat, of high value for tourism and biodiversity purposes. In many places, they are also important for recreational fishing. Australia has the largest areas of coral reefs in the world, and the last remaining large areas of coral reefs that can be considered to be in good condition. Their rarity imposes a global obligation on Australia to monitor and report on their condition. Measurement of their numbers, their type and the area covered by each is a crude surrogate for their condition. Remote sensing techniques may provide sufficient accuracy and precision to enable detection of major changes in live coral cover, providing an early warning of change to coral reef habitats in remote areas not frequently visited by tourists or scientists. Coral reefs are sensitive to changes in sea level, temperature, light climate and various pollutants, and might provide an ecological system for tracking the extent and rate of global climate changes (Wilkinson and Buddemeier 1994).

Analysis and interpretation

Changes in the area and number of viable coral reefs in each class provide a crude measure of condition. Apparently no baselines exist for the area of reefs of each class outside the Great Barrier Reef. Elsewhere, there are numerous studies of local areas. However, there appears to be no documented baseline of coral reef numbers and area by reef type at a regional scale.

The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes at a range of sites.

Monitoring design and strategies

Coral reefs are readily detected by remote sensing; satellite platforms (SPOT, TM), aerial photos and airborne video or scanner can all be used to map them. One of the satellite platforms will be most useful for regional-scale application but, as with other tools, detection of the seaward edge of the reefs may be highly uncertain, depending on topography and water clarity. The most appropriate mix of remote sensing tools can only be determined by pilot studies at a range of relevant spatial and temporal scales. Reefs may need to be measured at known stages of the tide, and an explicit model used to make repeated monitoring data comparable.

The area of coral reefs will change only slowly, so they should be assessed nationally on a 4-5 year cycle. The area of cover should be mapped to within 10 to 100 m of true position. This is readily achievable with modern positioning and navigational equipment, and is particularly critical with this habitat because of its patchy and sometimes linear nature in many localities.

Reporting scale

The number of reefs should be reported by IMCRA subregion, with the number of each reef type and the area of cover (km^2) of each type. The data should be aggregated upwards to Marine Regions for national-scale reporting. The area estimates for each reef type should be recorded for each IMCRA subregion with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables of number of reefs, reef types and area (km^2) by IMCRA subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Data for coral reefs in Queensland and for the Great Barrier Reef are held by the Great Barrier Reef Marine Park Authority, the Queensland Department of the Environment, and the Australian Institute of Marine Science. For some offshore islands, some data are held by Environment Australia (Biodiversity Group). In Western Australia, data on coral reefs are held by the Department of Conservation and Land Management. CSIRO holds data on coral reefs in the Torres Strait.

Linkages to other indicators

The number, location, area and type of coral reefs are related to various Pressure indicators in Class 6 Water/Sediment Quality, and Pressure and Response indicators in Class 7 Integrated Management. This indicator is also related to Biodiversity Indicators 11.1 and 11.2.

INDICATOR 2.4 DUNE VEGETATION

Description

This indicator is an estimate of the area of dunes covered by vegetation, and the main assemblage types, on the coastal fringes of the mainland and on the offshore islands and dependencies.

Rationale

Dune stability is related to vegetation cover. Also, dune vegetation comprises many native species and is an important habitat for many that are restricted to these harsh, dry and salt-enriched coastal conditions. Dunes are highly susceptible to a range of pressures that may happen over short and long time scales. These include local-scale problems such as recreation, roads and construction activities, as well as broad-scale problems such as changing climate and sea level. Beaches and dunes are highly valued for recreation, and for their intrinsic biodiversity. Change in the coverage of dunes by vegetation indicates increased instability, and this may be important in terms of dune movements, sand balance on regional scales, and loss of biodiversity.

This indicator is being developed as part of the Biodiversity theme. For details, refer to Saunders, *et al,* 1998

INDICATOR 2.5 INTERTIDAL REEF AREA

Description

This indicator is an estimate of the area of intertidal reef habitats in estuaries, on the coastal fringes of the mainland and on the offshore islands and dependencies.

Rationale

Intertidal reefs are key aspects of Australia's coastal environment. They are a primary recreational resource (for fishing, tide-pool education, snorkelling etc.), and in many places are subjected to intense harvesting of flora and fauna for human consumption. They also have considerable biodiversity value, particularly in areas distant from urban centres. They typically host a substantial diversity of flora and fauna that are adapted to withstand the harsh salt-enriched and desiccating environment. In and near estuaries, their existence and condition are threatened also by major changes in land uses and catchment management practices. Changes in sea level will substantially alter the area available to them, depending on local factors such as geomorphology and topography.

Analysis and interpretation

The area of intertidal reefs can be related to the nature and amount of sediment loads to estuaries, particularly in their upriver reaches. There appear to be no existing baselines for the area of intertidal reefs, although there are numerous studies of local areas that document the relevant areas at a fine scale. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

The intertidal reefs should be monitored using remote sensing tools. The most appropriate mix of such tools can be determined only by pilot studies at a range of relevant spatial and temporal scales, and across the relevant national scale of distribution of reefs. The pilot studies need also to compare the relative effectiveness of using area as opposed to linear dimensions, given the linear nature of this habitat. This work should be formed into an assessment of statistical power analysis comparing typical data sets for area and waterline length.

Intertidal reef area will change only slowly, so it should be assessed nationally on a 4-5 year cycle. The area of cover should be mapped to within 10 to 100 m of true position. This is readily achievable with modern positioning and navigational equipment and is particularly critical with this habitat, because of its linear nature.

Reporting scale

The areal extent (km^2) of intertidal reefs should be summarised and recorded for each estuary and IMCRA subregion in tabular form. The data should then be aggregated to Marine Regions, and subsequently nationally in additional tables. The extent of reefs should be recorded for each subregion, together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables of areas by IMCRA subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Numerous local studies have been carried out on intertidal reefs, but there are few regional or national data available. There appears to be no baseline of change in the area of intertidal reefs.

Linkages to other indicators

Intertidal reef area is closely related to the quality of intertidal reefs, and could be monitored in conjunction with this indicator. The area of intertidal reefs may decrease in conjunction with an increase in subtidal reef area in situations of sea level rise. The reefs may decrease in area in response to changes in land use in estuary catchments. Therefore this indicator will be related to a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management. This indicator is also related to Biodiversity indicators 11.1 and 11.2.

Indicator 2.6 Intertidal sand/mudflat area

Description

This indicator is an estimate of the area of intertidal sand and mudflat habitats by major sediment classes in estuaries, on the coastal fringes of the mainland and on the offshore islands and dependencies.

Rationale

Intertidal sand and mudflats are important habitats for valued species of fish, crustaceans and some species of seagrasses; they are used intensively near urban areas for bait collecting; and they support other important species such as migratory wading birds that are the subject of a number of international agreements. In the areas of Australia where there are high tide ranges, these habitats can be very extensive and hence ecologically important in maintaining a wide range of biodiversity, and as feeding grounds for many commercially and recreationally valued fish, molluscs and crustaceans. In and near estuaries, their existence and condition are threatened by major changes in land uses and catchment management practices. Changes in sea level will substantially alter the area available to them, depending on local factors such as geomorphology and topography and interactions with catchment characteristics.

Analysis and interpretation

The area of intertidal sand and mudflats can be related to the nature and amount of sediment loads to estuaries, particularly in their upriver reaches. There appears to be no existing baselines for the area of intertidal sand and mudflats, although there are numerous studies of local areas that document these habitats at a fine spatial scale. Changes in overall area, and changes in the major sediment classes, reflect major and gross changes in ecosystem characteristics that are likely to have substantial effects on the fauna of these habitats. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

The extent of intertidal sand and mudflats should be monitored using remote sensing tools. The sediment classes (probably only major ones — gravel, sand, mud, silt) will need to be carefully validated against real samples and a ground-truthing program based on reflectances and sediment analysis. The most appropriate mix of remote sensing tools can only be determined by pilot studies at a range of relevant spatial and temporal scales. These intertidal areas may need to be measured at known stages of the tide, and a standard area index computed based on an explicit model to make repeated monitoring data comparable.

The area of intertidal sand and mudflats will change only slowly, so they should be assessed nationally on a 4-5 year cycle. The area of cover should be mapped to within 10 to 100 m of true position. This is readily achievable with modern positioning and navigational equipment, and is particularly critical with this habitat because of its linear nature in many temperate localities.

Reporting scale

The areal extent (km^2) of each major sediment class in intertidal sand and mudflats should be summarised and recorded for each estuary and IMCRA subregion in tabular form. This should then be aggregated to Marine Regions, and subsequently nationally in additional tables. The extent of each sediment class in the sand and mudflats should be recorded for each subregion, together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables of areas by estuary and IMCRA subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Numerous local studies have been carried out on intertidal sand and mudflats, but there are few regional or national data available. There appears to be no existing baseline of change in the area of intertidal sand and mudflats.

Linkages to other indicators

The area of intertidal sand and mudflats is closely related to their quality, and could be monitored in conjunction with this indicator. This area may decrease in situations of sea level rise, depending on local topography, sediment dynamics and hydrodynamics. Changes (increases and decreases) in area of intertidal sand and mudflats may be related to changes in land use in estuary catchments. Therefore, this indicator will be related to a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management. This indicator is also related to Biodiversity indicators 11.1 and 11.2.

Indicator 2.7 Mangrove area

Description

This indicator is an estimate of the area of mangrove habitats and assemblages in estuaries, on the coastal fringes of the mainland and on the offshore islands and dependencies where mangroves occur.

Rationale

Mangrove habitats are important elements of estuaries and sheltered coastlines, mainly in the tropics. They are species-rich habitats, containing a diverse array of plants (39 species are termed mangroves) and many epiphytes, and they shelter numerous species of fish and invertebrates. They have important functions in providing habitat for the juvenile stages of many commercially important species of fish and crustaceans. They also stabilise sediments against coastal erosion processes. Australia has the third largest area of mangroves in the world. Mangroves are subjected to clearing for a variety of purposes including urban expansion, aquaculture projects and tourism ventures. However, in some estuaries mangroves readily colonise newly available sediments derived from the catchment. Mangroves are sensitive to various forms of pollution — notably oil pollution and air pollution — and to alterations in hydrological regimes such as change in the frequency of marine inundation or increased freshwater inundation.

Analysis and interpretation

Estimates of the area covered by individual assemblage types should be part of the analysis of the survey data. Changes in total area, and shifts in assemblage coverage, indicate major changes in environmental characteristics.

The methods used in the Cape York Peninsula Land Use Study (CYPLUS) (Danaher, 1995) are an appropriate model for a national approach. In temperate regions (south of Perth, and in South Australia and Victoria), only one species of mangrove exists, so mapping of total area only is required. Errors in the mapping and survey process should be estimated, or measured, and tracked throughout an aggregation process across individual patches of assemblages. The reported error rate (misclassification rate) for the CYPLUS methods is less than 20%, and this would be reduced by reductions in the number and types of assemblages reported. Important changes should be detectable at the 10% level of change in area. The level of important change will be more fully evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

Satellite imagery and aerial photography, or other remote sensing platforms, are the most likely candidates for area survey, with selected ground-truthing done perhaps by local government operations and community groups, and selected specialist surveys carried out by local research organisations. The methods used by CYPLUS seem to be efficient and effective, and could be adopted as the model for the overall survey strategy. In summary, this process used numerical classification techniques of TM satellite imagery, supported by aerial photographic interpretation and ground-truthing of selected sites. The distribution of mangroves was documented to the broad assemblage level, with ground-truthing undertaken at genus level.

Mangrove assemblages change only relatively slowly. The most substantial changes are found near urban areas where reclamation and other processes have operated to reduce their area. It is proposed, therefore, that mangrove area be surveyed nationally every 4-5 years, with annual (or more frequent) surveys of mangroves near major cities (Sydney, Newcastle, Brisbane, Townsville, Cairns and Darwin).

The defined assemblages and cover should be mapped to within 10 to 100 m of true position (see discussion of uncertainties in the introduction to Class 2: Habitat Extent).

Reporting scale

The areal extent (km^2) of each assemblage type should be summarised and recorded for each estuary and IMCRA subregion in tabular form. This should then be aggregated to Marine Regions, and subsequently nationally in additional tables. The extent of each assemblage should be recorded for each subregion, together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables of areas of each assemblage type by subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Satellite TM data are captured by satellite remote sensing centres (ACRES, WA Leeuwin Centre, etc.). Mangrove classifications and interpretations are conducted usually by the resource agencies in each State, and sometimes by the environment agencies. Data are mainly archived in raw form, not often as mapped areas of mangroves. Special-purpose studies have been undertaken in a number of States, and these have created a baseline of data. However, most studies have been carried out using different methods, and intercomparisons would be difficult.

Linkages to other indicators

Mangroves may be mapped as part of the mapping and survey of both saltmarshes and seagrasses. Indeed, mangrove area may increase at the expense of saltmarsh area in situations of sea level rise, or at the expense of seagrass beds in the case of increased sedimentation inputs to estuaries. Mangrove area will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management. This indicator is also related to Biodiversity indicators 11.1 and 11.2.

Indicator 2.8 Saltmarsh area

Description

This indicator is an estimate of the area of saltmarsh habitats, assemblages and their cover in estuaries, on the coastal fringes of the mainland and on the offshore islands and dependencies where saltmarshes occur.

Rationale

Saltmarshes are widely distributed in the tropical and temperate areas of Australia where there are protected or low-energy coastlines with a generally flat topography. The species diversity of saltmarsh plants seems to be highest in temperate regions; 173 species of plants have been recorded from southern New South Wales saltmarshes (Adam *et al.* 1988) compared with fewer than ten species in many tropical saltmarshes (Adam 1990). However, tropical saltmarshes cover much greater areas than temperate ones (Adam 1995). As habitat, saltmarshes are presumed to be highly productive, to have important roles as fish nurseries and to support other species of aquatic fauna, although there is little direct evidence for this. They are very important feeding and roosting areas for birds, including migratory waders covered by international agreements and locally rare species (including the orange-bellied parrot in Victoria). These values can be substantially degraded by various human activities and pressures, including oil pollution (Clarke and Ward 1994), land reclamation, grazing and trampling. Saltmarshes near urban areas are highly prized for urban expansion, and in the past have been used as landfill sites to raise the ground level sufficiently for subsequent use for housing, parks and recreational purposes.

Analysis and interpretation

Changes in both the area covered by individual assemblage types and total area indicate major changes in environmental characteristics. The level of important change will be more fully evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

There is little reliable national-scale baseline data. Although surveys have been undertaken, most regional-scale surveys have confounded various classes of saltmarsh vegetation, and clear boundaries have been difficult to define in some tropical open-coast environments (Adam 1995). A number of fine-scale surveys have been conducted (such as CSIRO 1994), so local baselines are available for some areas. These areas should be the focus of further and continuing intensive mapping and analysis of changes, supported by the national-scale mapping and monitoring described below.

Monitoring design and strategies

Satellite imagery and aerial photography, or other remote sensing platforms, are the most likely candidates for area survey, with selected ground-truthing done perhaps by local government operations and community groups, and selected specialist surveys carried out by local research organisations. The methods used by CYPLUS (described under Indicator 2.7) could be adopted as the model for the overall survey strategy. The distribution of saltmarshes could be documented at the broad assemblage level, with ground-truthing undertaken at genus level.

Saltmarsh assemblages change only relatively slowly. The most substantial changes are found near urban areas where reclamation and other processes have operated to reduce their area. It is therefore proposed that saltmarsh area be surveyed nationally each 4-5 years, with annual (or more frequent) surveys near major cities and regional centres.

The defined assemblages and cover should be mapped to within 10 to 100 m of true position.

Reporting scale

The areal extent (km^2) of each assemblage type should be summarised and recorded for each estuary and IMCRA subregion in tabular form. This should then be aggregated to Marine Regions, and subsequently nationally in additional tables. The extent of each assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables of areas of each assemblage type by subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Satellite TM data are captured by satellite remote sensing centres (ACRES, WA Leeuwin Centre, etc.). Data are mainly archived in raw form. Special-purpose studies have been undertaken in a number of States, and these have created a baseline of data for local places. Most studies, however, have been carried out using different methods, and intercomparisons would be difficult.

Linkages to other indicators

Saltmarshes may be mapped as part of the mapping and survey of mangroves and seagrasses. Saltmarsh area may decrease in situations of sea level rise, or be reduced by increased sedimentation inputs to estuaries. Saltmarsh area will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management. This indicator is also related to Biodiversity indicators 11.1 and 11.2.

Indicator 2.9 Seagrass area

Description

This indicator is an estimate of the area of intertidal and subtidal seagrass habitats and assemblages, and their cover in estuaries, on the coastal fringes of the mainland and near the offshore islands and dependencies where seagrasses occur.

Rationale

Seagrasses are highly valued for their intrinsic biodiversity, as well as being important as habitats for commercially and recreationally valued fish, mollusc and crustacean species. Many of the pressures that will affect Australia's marine and estuarine habitats are likely to be focused on intertidal areas in estuaries and shallow waters near the coast. Seagrasses are susceptible to many known pressures (pests, pollution, fishing, sea level change etc.), and changes in area reflect these and other pressures (Kirkman 1997).

Analysis and interpretation

Changes in both the area covered by individual assemblage types and total area indicate major changes in environmental characteristics. The level of important change will be more fully evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

There is little reliable national-scale baseline data. Although regional-scale surveys have been undertaken, most have not been able to establish clear boundaries for the seaward extent of subtidal seagrass beds. Also, in tropical areas highly turbid waters can often make mapping of subtidal seagrass beds a difficult task. CSIRO has a current program to map underwater features — including seagrass and algal beds — nationally, but this is at coarse resolution (1:100 000 scale). Recent surveys of deeper waters in Queensland and Western Australia using video and diver sampling have discovered large areas of previously unknown seagrass beds in waters down to 58 m depth (Lee Long *et al*. 1993; Anderson 1994; Lee Long *et al*. 1996a; Kirkman and Kuo 1996). Fine-scale surveys have also been conducted in many places (e.g. CSIRO 1994), so for some areas local baselines are available. Those areas already mapped in detail should be the focus of further and continuing intensive mapping and analysis of changes, supported by the national-scale mapping and monitoring described below.

Errors in the mapping and survey process should be estimated, or measured, and tracked throughout an aggregation process across individual patches of assemblages. The extent of change in either the overall area of beds or individual assemblages that is important is unknown. However, a precautionary approach would be to adopt the position that any detectable change is adverse. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes. In temperate seagrasses small amounts of change will be considered very important, but in some tropical seagrass beds changes of as much as 50% may be acceptable (Lee Long *et al*. 1996b).

Monitoring design and strategies

Satellite imagery, aerial photography and systematic towed video survey are the most likely candidates for regional area survey, with selected ground-truthing done perhaps by volunteers and community groups (such as tourist operators and dive clubs), and selected specialist surveys carried out by research organisations. The distribution of seagrasses will need to be documented to the broad assemblage level, with ground-truthing undertaken at genus level. Some of the appropriate tools and approaches are outlined in Kirkman (1996).

In temperate areas, seagrass assemblages change only relatively slowly. The most substantial changes are found near urban areas where pollution, reclamation and other processes have operated to reduce their area. It is therefore proposed that the area of temperate seagrass beds be surveyed nationally each 4-5 years, with annual (or more frequent) surveys of beds near major cities and regional centres.

Tropical seagrasses are more difficult to evaluate. The tools used for temperate seagrass mapping depend on clear water, or at least operate best in clear waters. Tropical waters are usually more turbid than temperate waters, although the turbidity of both is highly variable.

Detailed mapping of seagrasses — tropical and temperate — on a national scale will require an analysis of appropriate sampling tools and a pilot survey. The defined assemblages and cover should be mapped to within 10 to 100 m of true position.

Reporting scale

The areal extent (km²) of each assemblage type and cover class should be summarised and recorded for each estuary and IMCRA subregion in tabular form. This should then be aggregated to Marine Regions, and subsequently nationally in additional tables. The extent of each assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables of areas of each assemblage type and cover by subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Satellite TM data are captured by satellite remote sensing centres (ACRES, WA Leeuwin Centre, etc.). Data are mainly archived in raw form and not often as mapped areas of seagrasses. Special-purpose studies have been undertaken in a number of States, and these have created a baseline of data. Most studies, however, have been carried out using different methods, and intercomparisons would be difficult. CSIRO has conducted coarse-resolution mapping of seagrasses in Australian waters. The data gathered, together with those held by State agencies in most States, should form the basis for detailed evaluation and design of a more intensive national mapping program.

Linkages to other indicators

Seagrasses may be mapped as part of the mapping and survey of saltmarshes, mangroves and reefs. Seagrass area will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management. This indicator is also related to Biodiversity indicators 11.1 and 11.2.

Class 3: Habitat Quality

This group of indicators is designed to permit the integrity of the major habitats (from Class 2 above) to be assessed in a more detailed manner. Typically, these indicators rely on biological (species or assemblage-level) information. They have been selected to provide more detailed information about habitats than those in Class 2, and to be capable of detecting regional changes much earlier than those in Class 2.

Most of the key indicators in this class will need explicitly designed sampling programs. These indicators should be sampled according to carefully designed, national-scale, highly stratified sampling protocols. Each protocol will need to be based on a pilot-scale study in which the precise level of species and/or assemblages to be measured is explored and defined. Subsequently, the national sampling protocols should be designed to take into account the national distribution of the habitat, and its natural dynamics and variability. These sampling protocols should then be incorporated into a Standard Operating Protocol (SOP) that describes the complete process of sampling, interpretation and reporting (including quality assurance procedures) using the preferred national SoE techniques. This stratified national sampling protocol (and SOP procedures) should then be used to evaluate the quality of each nationally important habitat for each cycle of SoE reporting.

Habitat quality will need to be evaluated at fine spatial and temporal scales to obtain reliable data and information. Because of the potentially high cost of sampling programs, habitat quality will only be assessed at a limited number of places. To facilitate this process and maintain a national-scale perspective, it will be necessary to designate a suite of places, each with a set of suitably defined habitats, where sampling is routinely conducted to assess changes in the selected habitats. These places could be designated as a set of national reference sites, as priority areas for monitoring, or as a set of long-term ecological research sites. They would be designed to address both issue-specific objectives (such as the effects of major urban areas on specified habitat types) and objectives related to long-term natural change (to be able to discriminate anthropogenic change from the natural dynamics). The reference sites would be allocated by habitat and IMCRA subregion to ensure a suitable national coverage, and could be designed to build on existing centres of research knowledge (for example, they could be located near government coastal laboratories and university field stations, or in areas where detailed knowledge exists such as Cockburn Sound, Jervis Bay and Port Phillip Bay). The sites would be distributed amongst a small number of carefully selected refuge/reference areas (possibly nature reserves or marine parks) and other randomly and explicitly selected sites. Offshore regions would also be included, but here partnerships with appropriate resource users, such as the oil/gas and fishing industries, would be employed to designate relevant reference sites.

Monitoring at the reference sites would be designed to address the following objectives in terms of habitat quality:

1. to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems;

2. to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly;

3. to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats;

4. to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained (the ground truth for remote sensing techniques);

5. to act (in a very general way) as a form of control site for evaluating the importance of changes detected in other (finer-scale) monitoring programs that are part of, or linked to, SoE reporting; and

6. to provide finer-scale and more detailed evaluations (in space and time) of changes detected in indicators that cannot be studied in detail at the broad national scale.

Each Habitat Quality indicator will require the development of an SOP; the development of an SOP for each indicator is the next key step in the development of the detailed SoE specifications for each of the key indicators. This process will need to take into account, and be expressly designed to permit, a phased approach to implementation, matched to available resources. Each phase would need to explicitly address the issue of costs and associated risks.

In generic terms, each Habitat Quality indicator would comprise an assessment of the biological structure (species composition and abundances), selected important ecological functions (dependent on the habitat type), and potentially fine-scale detail on the growth rate or demographics of dominant or important taxa. For example, in soft sediment estuarine habitats processes such as bioturbation and nitrogen cycling in sediments might be key ones to be monitored, relating to nutrient impacts and eutrophication.

Each sampling program would be based on standardised sampling equipment, used in a defined and repeatable manner. It is clear and well recognised that this approach will not sample all species; the adoption of standard sampling tools and approaches is a reasonable compromise taking account of the cost and resource implications of sampling. Only a selected subset of the flora and fauna would be routinely sampled. In this sampling approach, detecting signal from "noise" is a classical ecological sampling design and analysis problem. There are several standard ways to determine the most cost- and resource-effective sampling strategies, and assess the statistical power of the sampling to detect change. The design and intensity of the standard sampling programs need to balance the need for statistical power against the need to be able to detect important changes in the flora and fauna.

Rapid assessment procedures may be useful in evaluating important environmental change, and there are a number of developing approaches that could be evaluated for SoE purposes. In the first instance, however, compromises such as reduced taxonomic resolution should be avoided until the implications of using such rapid assessment approaches have been fully evaluated (see for example Vanderklift *et al.* 1996). There are important and major gaps in our taxonomic understanding of the Australian marine flora and fauna and, although significant initiatives are under way (see for example http://www.mov.vic.gov.au/poly), our basic lack of a comprehensive taxonomic knowledge of the biota will continue to hamper appropriate assessment of the condition of the marine and estuarine environments.

In this class of indicators, as with the others, the space and time scales for sampling are to be determined as a process within the development of an SOP. The sampling time scales are related to the reporting frequency; reporting of changes for the purposes of SoE is to be carried out at about 4-5 year intervals. However, sampling for monitoring of indicators may be carried out at a range of scales. For example, monitoring of chlorophyll and nitrogen concentrations may be needed at daily or weekly intervals; the SoE reporting process would aggregate and synthesise the data to report on these indicators over the 4-5 year spans. The reporting scale described in this report refers only to the cycle of SoE reporting — not to the temporal scale for monitoring an indicator, which usually will need to be considerably more frequent.

Indicator 3.1 Algal bed species

Description

This indicator is a measure of the species composition and populations of subtidal algal-bed habitats. It comprises the resident flora and fauna that can usually be found in the algal beds, and temporary faunal species (such as fish and cephalopods) that may use the algal beds in an ephemeral manner.

Rationale

Marine and estuarine vegetated habitats are highly susceptible to a range of pressures that may occur on both short and long time scales. These include local-scale problems such as pollution and effects of fishing activities, as well as broad-scale problems such as changing climate and global pollution. Algal beds are highly diverse in temperate Australia, and are highly valued for their intrinsic biodiversity, as well as being important as habitats for commercially and recreationally valued species such as lobster and abalone. Many of the pressures that will be affect Australia's marine and estuarine habitats are likely to be focused on shallow waters near the coast. Algal beds are susceptible to many of the known pressures (pests, pollution, fishing, sea level change etc.), and changes in their species composition may indicate slow but important changes in the marine and estuarine ecosystems of which they are a part. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion, and at each reference site, change in the algal bed flora and fauna should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols, to be defined and developed for a specific SOP. The indicator would be monitored annually in the national reference sites for four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. Development of detailed techniques will need a specialised assessment and pilot study for each site and IMCRA subregion based on individual estuary catchments, pilot-scale studies, and an analysis of existing data on algal bed flora and fauna.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in each State have data on the algal bed flora and fauna gathered for specific fine-scale research studies, but there are no ongoing monitoring programs.

Linkages to other indicators

Whilst this indicator is mainly a measure of State (Condition), it is also a crucial indicator for interpreting changes that may be observed in the broad-scale measures of algal bed area (Class 2 indicator). Algal bed species composition may be monitored as part of an integrated national program focused on a set of national reference sites. Algal bed flora and fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

Indicator 3.2 Algal blooms

Description

This indicator documents the frequency of, and dominant species responsible for, algal blooms in estuaries and coastal waters. The indicator includes macroscopic algae (such as *Ulva*) and microscopic forms (such as *Trichodesmium*).

Rationale

Algal blooms have major detrimental effects on the environment. They degrade the recreational amenity of bathing beaches and the amenity for recreational pursuits on lakes, bays and estuaries. They can be toxic to humans, and may cause allergic responses in sensitive people and wildlife. They affect natural ecosystems by often causing massive de-oxygenation of bottom waters, killing resident flora and fauna. These effects may also degrade fisheries, both commercial and recreational, and have major detrimental consequences for tourism. The frequency of algal blooms is usually considered to be related to land-based sources of nutrients, and a reduction in inputs of nutrients leading to fewer algal blooms is the desired target for Australian waters (although not necessarily elsewhere, see Cherfas 1990).

Analysis and interpretation

Within each estuary, IMCRA subregion and Marine Region, changes in the frequency of, and dominant organisms in, blooms should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. Some baseline data exist in local government and State agencies, although the observational basis is mostly ad hoc and difficult to compare across jurisdictions.

Monitoring design and strategies

The data for this indicator will be captured by surveys by local government and State agencies. The bloom identification criteria need to be developed and promulgated in a national SOP for estuarine and marine algal blooms (perhaps similar to those being developed by the Eutrophication Program in the Land and Water Resources Research and Development Corporation's National River Health Initiative. These criteria would also ensure that blooms were classified according to their potential and actual toxicity to humans and wildlife. Where toxicity cannot be assessed or predicted, identification of the dominant organisms will be crucial. The SOP would also suggest more robust sampling and observational approaches to capture better-quality data on the frequency of blooms. These might involve training local community groups, volunteers and interested industries (such as aquaculture) to make routine observations of simple bloom parameters.

Reporting scale

The changes in bloom frequency should be summarised for each estuary, by each IMCRA subregion, and by Marine Region to comprise the national report. These changes should be recorded for each estuary and subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in bloom frequency and dominant species by estuary and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and government (local and State) agencies in each State have data on algal blooms gathered for specific fine-scale research studies, and some agencies keep records of reported blooms in some estuaries, but there are no ongoing systematic monitoring programs across subregions or larger scales.

Linkages to other indicators

This indicator is a measure of Pressure. It relates to indicators of water nutrients and others in Class 6 Water/Sediment Quality, various Condition indicators in Class 4 Renewable Products, and various indicators in Class 7 Integrated Management. Comparisons with indicator 3.17 chlorophyll concentrations will also be valuable.

INDICATOR 3. 3 BEACH SPECIES

Description

This indicator is a measure of the species composition and populations (intertidal and subtidal fauna) of beach habitats. It comprises the resident flora and fauna that can usually be found in, and immediately adjacent to, beaches. It includes resident fauna (beach infauna) and ephemeral species (fish, crustaceans and molluscs).

Rationale

Marine and estuarine habitats are highly susceptible to a range of pressures that may occur at both short and long time scales. These include local-scale problems such as pollution and effects of fishing activities, as well as broad-scale problems such as changing climate and global pollution. The fauna inhabiting beaches are highly diverse in both tropical and temperate Australia, and beaches are highly valued for their intrinsic biodiversity, as well as being important as habitats for commercially and recreationally valued species of fish. Many of the pressures that will be affect Australia's marine and estuarine habitats are likely to be focused on shallow waters near the coast. The fauna of beaches are susceptible to many of the known pressures (pests, pollution, fishing, sea level change etc.), and changes in their species composition may indicate slow but important changes in the marine and estuarine ecosystems of which they are a part. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the beach fauna should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in the national reference sites for four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be more robustly determined; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. Development of detailed techniques will need a specialised assessment and pilot study for each site and IMCRA subregion, based on individual estuary catchments and an analysis of existing data on beach fauna.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in each State have data on the beach fauna gathered for specific fine-scale research studies, but there are no ongoing monitoring programs.

Linkages to other indicators

Whilst this indicator is mainly a measure of State (Condition), it is also a crucial indicator for interpreting changes that may be observed in the broad-scale measures of beach area. Beach species composition may be monitored as part of an integrated national program focused on a set of national reference sites. The beach fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

Indicator 3. 4 Coral reef species

Description

This indicator is a measure of the species composition and populations of coral reef habitats. It comprises the resident flora and fauna that can usually be found on, and immediately adjacent to, the reefs. It includes resident fauna and species that may be ephemeral (such as fish).

Rationale

Coral reefs are highly susceptible to a range of pressures that may occur over short and long time scales. These include local-scale problems such as pollution and effects of fishing activities, and broad-scale problems such as changing climate and global pollution. Coral reefs are highly diverse in Australia, and are highly valued for their intrinsic biodiversity, as well as being important as habitats for commercially and recreationally valued fish species. Many of the pressures that will be affect Australia's marine and estuarine habitats are likely to be focused in shallow tropical waters near the coast where coral reefs flourish. Coral reefs are susceptible to many of the known pressures (pests, pollution, fishing, sea level change etc.), and changes in their species composition may indicate slow but important changes in the marine and estuarine ecosystems of which they are a part (Wilkinson and Buddemeier 1994). This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the coral reef flora and fauna species composition should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in the national reference sites for four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. The Australian Institute of Marine Science (AIMS) Long Term Monitoring survey techniques (manta tows and video techniques), supplemented as necessary, would be used as the basis for this work. AIMS has prepared Standard Operating Protocols (used in both long-term monitoring of the Great Barrier Reef and in several countries in the Pacific and Asia — see for example English *et al*. 1997; *Oliver et al*. 1995), and these should form the basis for the national coral reef health program. Some adaptations may be necessary to ensure that appropriate levels of biodiversity are fully included in the standard SOP — to expand the standard range of taxa — but this is feasible and achievable with some limited additional effort (Carleton and Done 1995). A range of publications on monitoring and assessment techniques is listed at the NOAA web site http://coral.aoml.noaa.gov/bib/lit.abstracts.html, and these should be consulted for a comprehensive analysis of other work on mapping and monitoring of coral reefs.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in Queensland, Western Australia, New South Wales and the Northern Territory have data on coral reef flora and fauna gathered for specific fine-scale research studies. AIMS and the Great Barrier Reef Marine Park Auhority (GBRMPA) have ongoing monitoring programs at various scales, and GBRMPA is developing a set of indicators for use in a "State of the Reef" report scheduled for 1998.

Linkages to other indicators

Whilst this indicator is mainly a measure of State (Condition), it is also a crucial indicator for interpreting changes that may be observed in the broad-scale measures of coral reef area. Coral reef species composition and populations may be monitored as part of an integrated national program focused on a set of national reference sites. The coral reef flora and fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

Indicator 3.5 Dune species

Description

This indicator is a measure of the species composition and populations of coastal dune habitats. It comprises the resident flora that can be usually found on the dunes, including vegetation from the mobile beach foredunes to the more stable rearward dune forests.

Rationale

Dune vegetation is highly susceptible to a range of pressures that may occur over short and long time scales. These include local-scale problems such as urban encroachment and effects of recreational uses, as well as broad-scale problems such as changing global climate. The species composition and distribution of dune vegetation is a surrogate for short- and long-term changes in the dune ecosystem.

This indicator is being developed as part of the Biodiversity theme. For details, refer to Saunders, *et al*, 1998

Indicator 3.6 Fish populations

Description

This indicator is a measure of the fish populations near beaches in estuaries, lagoons and bays and on sheltered parts of the coast.

Rationale

Many species of fish live in the shallow waters adjacent to beaches in bays and estuaries and on the coast at various times throughout their life cycle. These fish may be highly valued for recreational and commercial fishing purposes (see for example CSIRO 1994). Some are highly prized by recreational beach fishers, whereas others use the beaches for feeding or nursery grounds before moving into other areas where they become the target of commercial fisheries. Beach fishing is a popular recreational pastime in many estuaries and on sheltered coasts, and the fish populations may be subject to over-exploitation as well as the indirect effects of habitat destruction and coastal pollution. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Interpretation and analysis

Changes in fish populations using sheltered beaches can, like changes in other natural populations, be related to a number of possible factors. These include natural changes associated with fish populations, effects of climate change, effects of over-fishing (recreational or commercial, depending on the species concerned), or effects of pollution or habitat changes. At present, there are few baseline data on these fish, and so the trend in population sizes and distribution is unclear. Some local-scale studies have been conducted (such as CSIRO 1994) to establish baselines, and these may be used to evaluate changes that might be detected in the populations of these fish species.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on open coasts. The monitoring would have three purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of fishing and pollution can be determined more robustly; and to ensure rehabilitation programs can have a relatively undisturbed condition as a target for the restoration of degraded habitats. Development of detailed techniques for the SOP will need a specialised assessment and pilot study for each site and IMCRA subregion based on an analysis of existing data on beach fish populations. Monitoring may be carried out by community volunteers, in conjunction with routine science-based monitoring at a subset of locations. This should be explicitly designed into the SOP for this indicator.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in each State have data on the fish fauna gathered for specific fine-scale research studies, but there are no ongoing monitoring programs.

Linkages to other indicators

These fish may be monitored as part of an integrated national program spanning adjacent soft-sediment habitats such as seagrass habitats at national reference sites. The fish fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management, and this indicator will be related to indicator 4.3 fish catch.

Indicator 3.7 Intertidal reefs species

Description

This indicator is a measure of the species composition and populations of flora and fauna in intertidal reef habitats. It comprises the resident flora and fauna that can be usually found on the reefs.

Rationale

Intertidal reefs are highly susceptible to a range of pressures that may occur over short and long time scales. These include local-scale problems such as trampling, bait collecting, pollution and effects of fishing activities, as well as broad-scale problems such as changing climate and global pollution. Intertidal reefs are highly diverse in Australia, and are highly valued for their intrinsic biodiversity, as well as being important as habitats for recreationally valued species. Many of the pressures that will affect Australia's marine and estuarine habitats are likely to be focused in shallow waters near the coast where intertidal reefs exist. These species are susceptible to many of the known pressures (pests, pollution, fishing, sea level change etc.), and changes in species composition may indicate slow but important changes in the marine and estuarine ecosystems of which they are a part. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the intertidal reef flora and fauna species composition and populations should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on sheltered coasts. The monitoring would have four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be more robustly determined; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. The University of Sydney (Underwood and Kennelly 1990) has ongoing research programs that employ routine observational components to document the dynamics of flora and fauna on intertidal reefs, and these could form the basis for an SOP for the national SoE intertidal reef monitoring program.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in all States have data on intertidal reef flora and fauna gathered for specific fine-scale research studies.

Linkages to other indicators

This indicator should be closely linked to indicators of subtidal algal beds. The intertidal reef species composition and populations may be monitored as part of an integrated national program focused on a set of national reference sites. The intertidal reef flora and fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

INDICATOR 3.8 INTERTIDAL SAND/MUDFLAT SPECIES

Description

This indicator is a measure of the species composition and populations of fauna in intertidal sand and mudflat habitats. It comprises the resident fauna that can usually be found in the sediment, together with those ephemeral species (such as fish, crustaceans and molluscs) that use these habitats at high tide.

Rationale

Intertidal sand and mudflat habitats are highly susceptible to a range of pressures that may occur over short and long time scales. These include local-scale problems such as trampling, bait collecting, pollution and effects of fishing activities, as well as broad-scale problems such as changing climate and global pollution. Intertidal sand and mudflat habitats are highly diverse in Australia, and are highly valued for their intrinsic biodiversity, as well as being important as habitats for recreationally and commercially valued species. Many of the pressures that will be affect Australia's marine and estuarine habitats are likely to be focused in shallow waters near the coast where intertidal sand and mudflat habitats exist. These species are susceptible to many of the known pressures (pests, pollution, fishing, sea level change etc.), and changes in species composition may indicate slow but important changes in the marine and estuarine ecosystems of which they are a part. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the intertidal sand and mudflat species composition and populations should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on the open coast. The monitoring would have four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be more robustly determined; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. The Museum of Victoria has a project under way examining the possibility of using rapid assessment protocols to assess subtidal estuarine fauna, and similar approaches might be developed to form the basis of an SOP for the national SoE intertidal sand and mudflat habitats monitoring program. The Museum of Victoria also hosts a web site (http://www.mov.vic.gov.au/poly) that will assist with the taxonomy of polychaete worms, a common component of the infauna of soft sediment habitats.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in all States and the Northern Territory have data on intertidal sand and mudflat fauna gathered for specific fine-scale research studies.

Linkages to other indicators

This indicator should be closely linked to indicators of subtidal habitats, including algal beds. The intertidal sand and mudflat species composition and populations may be monitored as part of an integrated national program focused on a set of national reference sites. The intertidal sand and mudflat habitats will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management, particularly those relating to catchment management and land uses.

Indicator 3.9 Islands and cays species

Description

This indicator is a measure of the species composition and populations of marine flora and fauna of Australia's offshore islands and dependencies.

Rationale

Many of Australia's offshore islands and cays are of great importance for biodiversity reasons. Some are protected as parks or other forms of nature reserve, but there has been little systematic monitoring of the condition of marine flora and fauna both in reserves and in those cays and islands with other forms of land ownership/control. They are susceptible to broad-scale problems such as changing sea level, changes in climate and global pollution. This indicator would be measured in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems, and to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly. The reference sites would be able to act (in a very general way) as a form of control site for evaluating changes detected in other (finer-scale) monitoring programs on these islands and cays that are linked to SoE reporting. These islands and cays include those that are solely a Commonwealth responsibility (dependencies) and the many islands and cays that are State responsibilities.

Analysis and interpretation

At each reference site, change in the species composition and populations should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites for tracking the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems, and to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly. Preliminary inventories and analyses of the marine fauna of several National Nature Reserves exist, but there appear to be no ongoing monitoring programs in place for these or the other islands and cays.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each region together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and region, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each region.

Data sources

For Commonwealth islands and National Nature Reserves, existing inventories of species/assemblages are held by the Biodiversity Group in Environment Australia. Museums and research agencies in most States also hold some data relating to various offshore islands and cays.

Linkages to other indicators

This indicator should be closely linked to indicators of climate change, and to ocean processes relating to ocean-basin-scale circulation (indicator 8.2 sea surface temperature variability).

Indicator 3.10 Mangrove species

Description

This indicator is a measure of the species composition and populations of mangrove habitats. It comprises the sediment infauna and mangrove resident epifauna that can be sampled at low tide within the mangrove forests, and excludes migratory species (like fish) that use the mangroves in an ephemeral manner or only at high tide when sampling can be difficult.

Rationale

Mangrove habitats harbour a rich diversity of invertebrates. These range across a wide variety of taxonomic and functional groups, and many are relatively sedentary and constrained to living in mangrove habitats. Some, such as crabs, have critical ecological roles in the processing of mangrove leaf and other organic materials, and contribute greatly to the ecological values attributed to mangrove habitats. Mangroves are highly productive nursery grounds for many species of commercial value. These values can be substantially degraded by various human activities and pressures, including water pollution. The mangrove species themselves are resistant to a number of stresses, but the fauna inhabiting them may be considerably more sensitive to those stresses (such as heavy metal pollution). This means that, although the mangroves may persist, their areal extent is not necessarily a good surrogate for quality of the habitat. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the mangrove fauna should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on open coasts. The monitoring would have four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. Development of detailed techniques for the SOP will need a specialised assessment and pilot study for each site and IMCRA subregion based on individual estuary catchments and an analysis of existing data on mangrove fauna.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in each State have data on the mangrove fauna gathered for specific fine-scale research studies, but there are no ongoing monitoring programs.

Linkages to other indicators

Mangrove fauna may be monitored as part of an integrated national program spanning adjacent soft-sediment habitats such as saltmarsh and seagrass habitats at national reference sites. Mangrove fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

INDICATOR 3.11 PEST NUMBERS

Description

This indicator is a measure of the number and identity of introduced species documented to be pests in each estuary, IMCRA subregion and Marine Region, and the extent of the areas they infest.

Rationale

Marine pests have a wide range of destructive impacts on native biodiversity, harvested resources and cultured species, and potentially on humans at swimming beaches and waterside urban areas because of a reduction in recreational amenity.

Analysis and interpretation

Changes in the recorded numbers of pest species in various regions and subregions indicate both an increased awareness of pest species and their associated problems and changes in the numbers of species classified as pests. Species identified as pests are likely to be responsible for detrimental effects on fishing, aquaculture and recreational amenity, or on local biodiversity and ecological processes. The number of pest species is a subset of the number of species introduced to Australian ecosystems from other jurisdictions. The number of introduced species is likely to be much larger than that of recognised pest species because many introduced species are likely to be cryptic, and become recognised only when they create ecological or other problems. Within each estuary, IMCRA subregion and Marine Region, change in the number of documented pests and area of infestation should be assessed using univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be documented in conjunction with the CSIRO Centre for Research on Introduced Marine Pests, where national inventories will be maintained for the Australian Ballast Water Management Advisory Council. The specific protocols used will depend on the development of measurement and tracking procedures under the Ballast Water Management Strategy. These protocols should form the basis for a national SOP for SoE reporting purposes for marine pests. For some pests, particularly the macroscopic ones, monitoring might be assisted by volunteers organised and managed within community-based groups. Where volunteers are to have a role, they will need to operate under an appropriate SoE SOP.

Reporting scale

The changes in pest numbers and identities and area infested should be summarised by estuary, IMCRA subregion and Marine Region to comprise the national report. The changes should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with new pests documented, and tables summarising changes in pest numbers and area by subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion. The extent of areas affected should be summarised in tables accompanying each IMCRA subregion represented in the maps.

Data sources

The CSIRO Centre for Research on Introduced Marine Pests holds considerable data on marine pests and their distributions. State fisheries and environment agencies also hold considerable data on pest species in their local areas.

Linkages to other indicators

This indicator is closely linked to indicator 7.14 ship visits, to various other indicators of Habitat Quality, and to Biodiversity indicator 3.2.

Indicator 3.12 Saltmarsh species

Description

This indicator is a measure of the species composition and populations of saltmarsh habitats. It comprises the plant species, the sediment infauna and saltmarsh resident epifauna that can be sampled at low tide within the saltmarshes, but excludes the migratory species (like fish) that use the saltmarshes in an ephemeral manner.

Rationale

Saltmarshes are widely distributed in the tropics and temperate areas of Australia with protected or low-energy coastlines and with generally a flat topography. Saltmarsh habitats harbour plants and invertebrates that may contribute greatly to the ecological values of shallow-water ecosystems. As a habitat, they support a number of species of recreational and commercial value. These values can be substantially degraded by various human activities and pressures, including oil pollution (Clarke and Ward, 1994), land reclamation and trampling. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the saltmarsh species and assemblages should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites. The monitoring would have four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. Development of detailed techniques for the SOP will need a specialised assessment and pilot study for each site and IMCRA subregion based on individual estuary catchments and an analysis of existing data on saltmarsh species and assemblages.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major universities, herbariums and museums in each State have data on the saltmarsh flora and fauna gathered for specific fine-scale research studies, but there are no ongoing monitoring programs.

Linkages to other indicators

Saltmarsh flora and fauna may be monitored as part of an integrated national program of monitoring spanning adjacent soft-sediment habitats such as mangrove and seagrass habitats at national reference sites. Saltmarsh flora and fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

INDICATOR 3.13 SEAMOUNT SPECIES

Description

This indicator is a measure of the species composition and populations of faunal species occupying seamount habitats. It includes the resident epifauna that can be sampled with non-destructive sampling tools, as well as the migratory species (such as fish) that may use the seamounts in an ephemeral manner.

Rationale

There are many seamounts in Australia's Exclusive Economic Zone (EEZ), and more than 50 have been documented recently (1994) in southern Australian waters by the Australian Geological Survey Organisation (AGSO). Other seamounts occur off the east coast (associated with the Lord Howe Rise and the Coral Sea Plateau). However, little is known of the biology of Australian seamounts. Recent studies have suggested that their fauna is intensely endemic (Koslow 1997). Some of these seamounts may not have been fished in destructive ways, and this has prompted research on the identification of a set of seamounts that might be useful for protection (Koslow and Exon 1995). The condition of the protected and fished seamounts may be used to assess the effects of fishing practices, and to track natural dynamics and change in these deep-water communities. Natural (or very slow) changes in the fauna of these seamounts may reflect changes in ocean conditions in the long term (such as might be expected as the climate gradually changes). The seamount fauna may be well positioned to document any slow changes in the ocean environment far from, and independent of, the influences of land-based runoff and inputs. This indicator would be measured in a small number of carefully selected refuge/reference seamounts chosen to represent a range of those present within the EEZ.

Analysis and interpretation

Within each IMCRA subregion and at each seamount, change in the species and assemblages should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using towed video, and possibly acoustic, sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored in a small number of carefully selected refuge/reference seamounts to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems, and to provide the basis for control/reference conditions so that local-scale effects of seamount fishing activities can be determined more robustly. Development of detailed techniques for the SOP will need a specialised assessment and a pilot study following an analysis of existing data on seamount species and assemblages. Natural change on seamounts is probably slow, and where specific impacts from fishing or mining activities are not likely the monitoring of seamounts would probably be conducted on a 4-5 year cycle to be coherent with SoE reporting cycles. However, if only small changes in the seamount fauna are deemed to be critical — if, for example, the seamount fauna are determined to be intensely endemic and small changes are likely to reflect important changes — then monitoring may need to be more frequent to be able to detect these changes.

Reporting scale

The changes in species composition and/or assemblage composition at each seamount should be summarised by seamount, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by seamount and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

CSIRO Division of Marine Research has studied a number of seamounts south of Tasmania and holds data on the fauna, but there are no ongoing monitoring programs. Other seamounts in the EEZ remain to be studied.

Linkages to other indicators

Seamount fauna may be closely related to indicators of climate change and to indicators of fish catch.

INDICATOR 3.14 SEAGRASS SPECIES

Description

This indicator is a measure of the species composition and populations of subtidal and intertidal seagrass habitats. It comprises the plant species, the sediment infauna, and seagrass resident and temporary epifauna (such as some fish, crustaceans and molluscs) that use the seagrasses in an ephemeral manner.

Rationale

Marine and estuarine vegetated habitats are highly susceptible to a range of pressures that may occur over both short and long time scales. These include local-scale problems such as nutrient pollution and effects of fishing activities as well as broad-scale problems such as changing climate and sea level. Seagrasses are highly valued for their intrinsic biodiversity, as well as being important as habitats for commercially and recreationally valued fish, mollusc and crustacean species. Many of the pressures that will affect Australia's marine and estuarine habitats are likely to be focused on intertidal areas in estuaries and shallow waters near the coast. Seagrasses are susceptible to many of the known pressures (pests, pollution, fishing, sea level change etc.), and changes in their species composition may indicate slow but important changes in the marine and estuarine ecosystems of which they are a part. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the seagrass species and assemblages should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured in annual assessments of the seagrass flora and fauna using traditional sampling protocols to be defined and developed in a specific SOP. For epibenthic fauna, the recommended approach is the small towed beam trawl (Ward and Young 1982) because of its ease of operation and the existing Australian data that have been collected with this sampling tool. For flora, a combination of line transect, quadrat and leaf-blade scales is required. The indicator would be monitored annually in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on open coasts. The monitoring would have four purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats; and to ensure that broad-scale changes detected in the indicators that monitor Habitat Extent may be interpreted and changes explained. Development of detailed techniques for the SOP will need a specialised assessment and pilot study for each site and IMCRA subregion based on individual estuary catchments and an analysis of existing data on seagrass species and assemblages.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major universities, herbariums and museums in each State have data on the seagrass flora and fauna gathered for specific fine-scale research studies, but there are no ongoing monitoring programs.

Linkages to other indicators

Seagrass flora and fauna may be monitored as part of an integrated national program of monitoring spanning adjacent soft-sediment habitats such as mangrove and intertidal sand and mudflat habitats at national reference sites. Seagrass flora and fauna will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

Indicator 3.15 Species outbreaks

Description

This indicator is a measure of the number (and the identity) of native species that outbreak in population explosions (or blooms), and the general locations and areas affected.

Rationale

A number of naturally occurring species have been documented as outbreaking, involving large population explosions. These rapid increases can threaten other native species and commercially valuable resources. Outbreaks of Crown of Thorns starfish and *Drupella,* for example, threaten coral reefs and tourism values. Although the causes of these and other outbreaks are not well understood, a number of hypotheses suggest that they may be related indirectly to the effects of human activities, or be enhanced by them.

Analysis and interpretation

Changes in recorded number of outbreaking species in the IMCRA subregions and Marine Regions will indicate both an increased awareness of these species and their associated problems and actual changes in the number of species outbreaking. Species identified as outbreaking are likely to have detrimental effects on fishing, on aquaculture, on recreational amenity, or on local biodiversity and ecological processes. Within each IMCRA subregion and Marine Region, change in the number of outbreaking species and the area affected should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be documented in estuaries, lagoons and bays and on coasts on an annual basis in conjunction with State and local government agencies. Reporting procedures will need to be the subject of a specific national SOP to be developed for SoE reporting purposes.

Reporting scale

The changes in number of outbreaking species, their identities, and the areas affected should be summarised by IMCRA subregion and Marine Region to comprise the national report. The changes should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with new outbreaking species documented and tables summarising changes in outbreaking species numbers and area by subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Data on outbreaking species are mainly held by State agencies responsible for environmental management and conservation. For the Great Barrier Reef (Crown of Thorns starfish), GBRMPA and AIMS also hold a substantial proportion of the available data.

Linkages to other indicators

This indicator is linked to various other indicators of Habitat Quality, and is critically linked to a range of indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management.

Indicator 3.16 Subtidal sand/mudflat species

Description

This indicator is a measure of the species composition and populations of fauna in shallow (<20 metres depth) subtidal sand and mudflat habitats. It comprises the resident fauna that can usually be found in the sediment, together with those ephemeral species (such as fish, crustaceans and molluscs) that use these habitats from time to time.

Rationale

Subtidal sand and mudflat habitats are highly susceptible to a range of pressures that may occur over short and long time scales. These include local-scale problems such as pollution and effects of fishing activities, as well as broad-scale problems such as changing climate and global pollution. Subtidal sand and mudflat habitats are highly diverse in Australia, and are highly valued for their intrinsic biodiversity as well as being important as habitats for recreationally and commercially valued species. Many of the pressures that will be affect Australia's marine and estuarine habitats are likely to be focused in shallow waters near the coast where subtidal sand and mudflat habitats exist. They are susceptible to many of the known pressures (pests, pollution, fishing, sea level change etc.), and changes in their species composition may indicate slow but important changes in the marine and estuarine ecosystems of which they are a part. This indicator would be monitored in the national reference sites to address the objectives described in the introduction to Class 3: Habitat Quality.

Analysis and interpretation

Within each IMCRA subregion and at each reference site, change in the subtidal sand and mudflat species composition and populations should be assessed using multivariate statistical analyses to summarise change. Individual numerically dominant species should be assessed by univariate statistical approaches using explicit statistical models. The level of important change will be evaluated by assessment of the time-series of monitoring data, and an assessment of the trajectory of changes.

Monitoring design and strategies

This indicator would be measured using traditional sampling protocols to be defined and developed for a specific SOP. The indicator would be monitored annually in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on the open coast. The monitoring would have three purposes: to track the slow natural change and the global changes that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; and to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats. The Museum of Victoria has a project under way examining the possibility of using rapid assessment protocols to assess subtidal estuarine fauna, and similar approaches might be developed to form the basis for an SOP for the national SoE subtidal sand and mudflat habitats monitoring program.

Reporting scale

The changes in species composition and/or assemblage composition in each reference site should be summarised by site, by IMCRA subregion, and by Marine Region to comprise the national report. The changes in each species/assemblage should be recorded for each subregion together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in each species/assemblage by site and subregion, together with tables summarising the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion.

Data sources

Major research institutions, universities and museums in all States and the Northern Territory have data on subtidal sand and mudflat fauna gathered for specific fine-scale research studies.

Linkages to other indicators

This indicator should be closely linked to indicators of intertidal habitats, including algal beds, and to other subtidal indicators. The subtidal sand and mudflat species composition and populations may be monitored as part of an integrated national program focused on a set of national reference sites. The subtidal sand and mudflat habitats will be critically influenced by a range of Pressure and Response indicators in Class 6 Water/Sediment Quality and Class 7 Integrated Management, particularly those relating to catchment management and land uses.

INDICATOR 3.17 CHLOROPHYLL CONCENTRATIONS

Description

This indicator is the annual median concentration of chlorophyll in each distinguishable body of marine and estuarine water.

Rationale

The concentration of the photosynthetic pigment chlorophyll a (referred to as chlorophyll) in marine waters is a proven indicator of the biomass of microscopic plants such as unicellular algae. It can be employed to give an estimate of primary production, but there is not necessarily a rigorous or coherent relation between biomass and primary productivity. Remote sensing, using colour scanners, from either aircraft or satellites can be a cost-effective means of gathering chlorophyll data, depending on several design issues (Wallace and Campbell 1997). However, it needs established algorithms for different waterbodies that have been validated by ground-truthing. Individual taxa (classes, families and sometimes genera) of phytoplankton can be identified by characteristic pigment signatures (chlorophylls and accessory pigments) after separation of pigment extracts by high performance liquid chromatography (Wright *et al.* 1991).

Analysis and interpretation

Anomalously and consistently high concentrations of chlorophyll in waterbodies need to be distinguished from the variation of chlorophyll with latitude, its changes with season, and its association with hydrodynamical features in coastal and oceanic waters (e.g. upwelling, eddies and fronts). Very limited information exists currently to make this distinction.

Standard methods need to be applied for chlorophyll extraction. Frequent comparison and validation of laboratory spectrophotometric and spectrofluorometric methods for directly determining chlorophyll are required; HPLC analysis of pure cultures could serve as a reference method. Indirect methods of determination, such as the use of *in situ* fluorescence or an ocean colour scanner (remote sensing), must be ground-truthed or calibrated using direct methods of analysis. Furthermore, algorithms must be fully validated and interferences in the measurements should be corrected for.

Increases in the annual median concentrations of chlorophyll in individual waterbodies may be related to gradual changes in nutrient status, and to increasing eutrophication status.

Monitoring design and strategies

Temporal scales: Chlorophyll levels vary on a wide range of time scales. This variation is not only a result of the influence of inputs and passive transport; in addition some microalgae are able to migrate vertically to take advantage of favourable conditions. Therefore, field surveys need to be conducted as frequently as practicable to detect change against the background of natural variability. It is very beneficial if these surveys can be associated with sampling for other water quality parameters, such as water nutrients (nitrogen). If an ocean colour scanner is used to obtain chlorophyll data, the frequency of measurement will be set by the return interval of the remote sensing platform. Advantages of the latter approach include synoptic coverage of large areas of water and, if an airborne scanner is used, the possibility that data can be obtained at times of interest; a disadvantage is that inclement atmospheric conditions (cloud, storms etc.) can prevent measurements. Automated field instrumentation will also have a place in local high-frequency monitoring of chlorophyll (via an *in situ* fluorescence technique).

Spatial scales: Chlorophyll data are useful from scales of small coastal waters (estuaries, lagoons and inlets) up to shelf seas. Individual stations in key locations, when monitored over time, can give valuable insight into chlorophyll levels and are useful for ground-truthing. The CSIRO coastal station network and international oceanic time-series stations fulfil, or are proposed to fulfil, this role.

Survey strategy: For field surveys, it would be invaluable for future interpretation to tie in chlorophyll measurements with those of turbidity and the nutrient nitrogen. Since many of the algal blooms and much of the eutrophication in estuarine and coastal waters are thought to be the result of terrestrial human activities, estuaries are an appropriate monitoring location for land run-off. They act both as a filter and as a channelling conduit between land and sea, and are thus sensitive to change. A selection of estuaries that were regularly monitored around the nation, in a set of national reference sites, should be useful in assessing regional conditions. Choice of estuaries within regions could be on the basis of catchments characterised by different land uses — urban/industrial, rural, mining/forest operations or undisturbed landforms (national parks, "old-growth" forest or similar). A two-tiered monitoring scheme is proposed:

- intermittent sampling together with measurement of other water quality indicators; and
- continuous sampling at a master station.

Within each estuary, a sub-sampling approach could involve five sites, sampled monthly. At each site, surface and bottom water samples would be collected and analysed for chlorophyll. *In situ* fluorimetric sensors are well suited to automated monitoring of chlorophyll. One of the five stations used for intermittent estuarine sampling should also be identified as the "master" station, at which an automatic chlorophyll monitor (most likely coupled with automated measurement of temperature, conductivity and turbidity) is installed. It would continuously sample at the surface and near the bottom. Incorporation of this sampling program into existing estuarine surveys done by State agencies or other organisations would be advantageous. Also recommended is the integration of State data on major enclosed and semi-enclosed coastal waterways (bays, lagoons etc.) into SoE reporting, since these systems have been prone to eutrophication in the Australian context.

Remote sensing — especially using satellite-mounted colour scanners (SeaWiFS and similar platforms) — is advocated for broad-based monitoring of chlorophyll once appropriate algorithms have been developed and proved. Aircraft-mounted systems can be used to provide more detailed information on areas of interest, or to operate when satellite coverage is not available. These activities would complement field surveys, where a tight relation between chlorophyll and other water quality parameters is maintained. Field surveys will still be needed to provide information for sub-surface waters because of the limited depth penetration of remote colour scanners (especially in turbid waters).

The detail of a monitoring program for SoE reporting will need to be developed and defined in an appropriate SOP.

Reporting scale

This indicator should be reported at national, State and regional level — with increased spatial and temporal resolution in that order. At the national level, annual reporting will be made from monthly measurements (or from monthly consolidated statistics from the automatic chlorophyll station) in specified key estuaries and coastal waterbodies; additional sites could be reported from approved monitoring by State and local governments.

Outputs

National reporting of chlorophyll is probably most easily represented by maps displaying the number of estuaries and other inshore waterbodies in classes of annual median chlorophyll concentration. At the IMCRA subregion scale, the data may be best displayed using maps showing actual classes of annual median chlorophyll concentrations for each waterbody. Sufficient baseline data exist to establish a range of classes. Once sufficient SoE information on chlorophyll is available, it will be possible to include annotated tables on the maps summarising trends for the indicator and showing the statistical significance of the trends. These trends should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Data sources

Scattered data exist for estuaries and coastal and oceanic waters around Australia, but some may be of dubious quality. State agencies, Commonwealth institutions and universities have most of the data. The best-studied time-series data for chlorophyll, using reliable methods, has been obtained for the Port Hacking (100 m) coastal station off Sydney (see Hallegraeff and Jeffrey 1993).

Linkages to other indicators

For effective use of the chlorophyll indicator, the results should be correlated with data from the water quality indicators 6.3 turbidity and 6.4 water nutrients (nitrogen), and evaluated in combination with Habitat Quality indicators.

Class 4: Renewable Products

These are indicators that document the various aspects of the nature and production of marine and estuarine living resources. In a very broad sense, continued production of marketable marine products is related to a healthy set of ecosystems, and so production level is a useful — although crude — indicator of the condition of the marine and estuarine ecosystems from which the products are derived.

Indicator 4.1 Aquaculture effort

Description

This indicator is a measure of the number and extent of aquaculture facilities in Australia, and their type of operation. Aquaculture can be classified into two types: the maintenance of plants and animals in the existing marine environment (such as the cage culture of salmon), and the culture of animals and plants in intensively modified habitats (such as prawn ponds).

Rationale

Aquaculture facilities may pose an important potential threat to native species because of habitat modification and local pollution impacts, and because of their potential to spread diseases into wild populations. Aquaculture facilities may also use habitats of value to other commercial ventures, including wild fisheries. Escapees from aquaculture operations also may have important effects on local gene pools, and compete with native species.

Analysis and interpretation

The number of aquaculture operations by type (see below) and the area included within each operation represents the potential for direct habitat modification, the potential for local pollution impacts, and the possible extent of the threat of disease introduction and genetic effects in wild populations. Care needs to be exercised when interpreting some data because of the tendency for shore-based facilities to be established on sites of previous aquaculture ventures or other similar activities such as salt ponds. Data on previous uses of the areas should be examined to assess the real importance of the development of aquaculture on sites abandoned from other uses; it is conceivable that aquaculture uses improve the environmental quality of some sites previously used for more destructive or polluting uses.

Monitoring design and strategy

The State agencies responsible for approving and managing aquaculture operations (usually Departments of Fisheries and Environment Protection Agencies) should be surveyed for the following information for each existing aquaculture venture or location on an annual basis where appropriate: location (spatial coordinates); environment used (estuary, bay, ocean, shore-based etc.); nature of the aquaculture operation (longline, cage, earth pond, plastic tank etc.); number of units and their total area of coverage (ponds, cages etc.); target species; projected annual production capacity; water recycling capacity (as proportion of total water usage); type of waste water treatment process used; food types used; and annual quantity of each food type used.

These agencies should also be censused for the number and type of applications pending — in the approvals process — and the proposed locations of these ventures, with as much of the additional detail (above) as possible collected.

Reporting scale

The number, type and total area of aquaculture operations, and the additional attributes described above, should be reported by individual catchment, by IMCRA subregion, and by Marine Region on an annual basis. The annual data for each estuary, subregion and Marine Region should be reported in tabular form. The differences between these data and any previous (or baseline) estimates should then be expressed as graphs of change showing annual data — for individual estuaries, for IMCRA subregions, and for the national summary at the scale of Marine Regions.

Outputs

The outputs would be in the form of graphs and tables for the estuary scale, and as maps for IMCRA subregions and the Marine Regions. The maps would show the locations of the aquaculture ventures and operations by number, type and area, and annual changes.

Data sources

The data on aquaculture are held and managed by the State agencies, mainly the fisheries agencies.

Links to other indicators

This indicator is closely linked to indicator 4.2, aquaculture production, and to those in Water/Sediment Quality.

INDICATOR 4.2 AQUACULTURE PRODUCTION

Description

This indicator is a measure of the annual production of the most valuable (top 25 in any year) cultured species of fish, invertebrates and plants.

Rationale

This indicator is designed to track the commercial production of aquaculture species, and the potential for this to have impacts on the environment. It is constrained to the production of the top 25 species (by dollar value) each year. The area used in aquaculture production has only limited value for assessing impacts of aquaculture on a national basis as the different types of aquaculture operations have very different actual and potential impacts on the environment. The need for feeding is a major difference in types of aquaculture operation, distinguishing ventures like mussel and oyster culture from salmon cages and prawn ponds. As more intensive forms of aquaculture develop, the balance between production of non-fed and fed classes of products is likely to change. These changes have implications for the sustainability of aquaculture and for risks to the environment, and may be related to changes in wild harvest fisheries.

Analysis and interpretation

Increased efficiency over time may result in increased production from aquaculture ventures without increased pressures on the environment. Thus analyses of total production (documented in the same terms as in indicator 4.1 above) will be able to assess and report on the extent to which new processes and environmental safeguards are being implemented coupled with increases in production. The balance between fed and non-fed products is a key component in assessing the impact of aquaculture. If the mix of species, and their dollar values, changes rapidly in the list of the top 25 species, this may be a useful indicator of non-sustainability for particular species or types of aquaculture.

Monitoring design and strategy

This will involve surveying the relevant State agencies for annual data on production values ($) and biomass produced for each species cultured. The data recorded would be for each venture or operation (as in Indicator 4.1): species, total weight of production, and market value of production.

Reporting scale

The data on species production and value should be reported by individual catchment, by IMCRA subregion, and by Marine Region on an annual basis. The annual data for each estuary, subregion and Marine Region should be reported in tabular form. The differences between these data and any previous (or baseline) estimates should then be expressed as graphs of change showing annual data — for individual estuaries, for IMCRA subregions, and for the national summary at the scale of Marine Regions.

Outputs

The outputs would be in the form of graphs and tables for the estuary scale, and as maps for IMCRA subregions and the Marine Regions. The maps would show the amount and value of production by type and area, and annual changes.

Data sources

The data on aquaculture are held and managed by the State agencies, mainly the fisheries agencies.

Links to other indicators

This indicator is closely linked to indicator 4.1 Aquaculture production, and to those in Water/Sediment Quality.

INDICATOR 4.3 FISH STOCKS

Description

This indicator documents annually, for each of the top 25 species (or species groups) ranked by dollar value, the total landed value, the total catch weight, an assessment of the stock and the formal status of the fishery.

Rationale

Catch, on its own, is a not a good measure of the health of the accessible stocks of commercially exploited fish, crustaceans and molluscs because it is confounded by changes in fishing effort, and is obviously susceptible to many other aspects of fisheries management such as the setting of quotas as well as to environmental changes and natural dynamics. Annual stock assessments are carried out for the main commercial fish stocks. These take into account variables such as changes in catch rates, size and composition of the stock, and market conditions. They can be used to evaluate the resource sustainability of Australian fishing in the broadest sense, and the condition of Australia's commercial fish stocks.

Analysis and interpretation

Each major fished species under Commonwealth control, and several of those under State control, are subjected to a regular detailed (often annual) evaluation and stock assessment. These assessments include an evaluation of trends in the stock based on catch and effort, and recommendations for future sustainable harvesting levels. Changes in rank in the table of the top 25 taxa, and changes in absolute catch levels, can be interpreted to assess resource sustainability. In the long term, where stock evaluations and harvesting predictions are correct, and where management controls are effective, the mixture and rank of species in the top 25 will be relatively stable, or change only slowly.

Monitoring design and strategies

The distribution of many of the major fished stocks is not consistent with the IMCRA subregions or Marine Regions, and some species (such as tuna) are highly migratory and pass through many subregions and Marine Regions. Data should be collected annually from the relevant fisheries agencies and reported by defined fishery boundaries, but also by IMCRA subregion or Marine Region where the fisheries are contained wholly or mainly within a subregion or Marine Region.

Reporting scale

The extent of changes in stock structure in each of the species, together with their values, catches, trends and status, should be aggregated at IMCRA subregion (if appropriate) and Marine Region level into summary reports at the national scale. This will not be possible for some fisheries; they should be reported on a fishery basis.

Outputs

The extent of changes in stock sizes, values, catches, trends and status should be presented in graphical formats. These will be aggregated at IMCRA subregion (if appropriate), Marine Region and/or fishery level into summary tables at the national scale, supported by map outputs where appropriate.

Linkages to other indicators

This indicator should be linked to indicator 4.5 trawl fishing areas, and to indicators in Class 7 Integrated Management.

INDICATOR 4.4 SEAFOOD QUALITY (CONTAMINATION)

Description

This indicator covers the number of samples of seafood species that have concentrations of contaminants exceeding Maximum Recommended Limits (MRLs); the effort expended on national monitoring of these residues; the type, number of occurrences, and severity of food poisonings or other acute seafood-based problems; and the extent of post-harvest treatment facilities required to manage these problems.

Rationale

The quality of Australian seafood is generally good. However, there are times and places where contaminants may be present. These may be naturally occurring substances such mercury and other heavy metals, or synthetic chemicals such as pesticides or industrial waste products. The public and seafood consumers need to be assured that seafood remains clean and safe to eat, and that routine monitoring is sufficient to detect contamination problems when they arise. The frequency of occurrence of samples not meeting accepted standards, and the type, frequency and severity of food poisoning or other acute seafood problems, will adequately document these issues related to seafood quality. To ensure that national-level monitoring is adequate to detect seafood contamination, should it occur, the statistics on incidents must be accompanied by information on the effort put into monitoring for potential exceedances.

Analysis and interpretation

Changes in the number of samples that exceed MRLs may have several causes. These include: changes in fishery management practices (such as opening new fishing grounds, permitting harvest of older or younger individuals, etc.); exposure of the fish stock to a pollution incident; or a change in the effort put into monitoring to detect exceedances. Some species, such as mussels and oysters, are grown in coastal areas that can, at times, become polluted with sewage or other wastes. This may lead to outbreaks of food poisoning in consumers of these species of seafood. The locations, frequency and severity of such outbreaks are a useful, although extreme, indicator of environmental (mainly water) quality. The utility of this information depends on a knowledge of the cleansing processes to which these species must be subjected after they are harvested.

Monitoring design and strategy

State and Commonwealth health and fisheries authorities should be surveyed to seek data on: the number of MRL exceedances and number of samples tested, all by species and by individual contaminant and location; and the number of acute food poisoning events together with, for each one, the causal agent, seafood species responsible, location, and duration of the problem. Fisheries and aquaculture management agencies should also be surveyed for data on the type, location, number and capacity of treatment facilities installed to combat seafood contamination problems.

Reporting scale

Where possible, the data should all be reported by estuary and IMCRA subregion, and be summarised to the national scale by Marine Region. For some, reporting may only be feasible by fishery since trace-back data may not be available to identify the precise location where individual animals were captured.

Outputs

The number of exceedances of each MRL, the contaminant and species responsible, the number of samples of each species analysed, and the type, number of occurrences, and severity of food poisonings or other acute seafood-based problems should all be reported using annual data in graphs and tables for each estuary, IMCRA subregion and Marine Region where possible. The type, location, number and capacity of treatment facilities installed to manage these problems should also be reported for each estuary, and summarised by IMCRA subregion and Marine Region. These data should be summarised onto map outputs wherever possible.

Data sources

Considerable amounts of existing data are held by State and Commonwealth health and fisheries authorities, although some have been determined to be not available for public release.

Links to other indicators

This indicator is closely allied to those in Water/Sediment Quality.

Indicator 4.5 Trawl fishing area

Description

This indicator covers the area swept by demersal (bottom) trawling of different types by fishery, subregion and Marine Region, the location of trawl fishing grounds, and the distribution of frequency of trawling over individual places in each trawling ground.

Rationale

Demersal trawling has a substantial impact on natural marine systems, with the severity of the effect related to both the frequency of trawling in a particular place and the nature of the benthic (bottom-dwelling) plant and animal assemblages that would normally live in that place. Many mobile animals, including fish, crustaceans and molluscs, live in association with the sedentary benthic fauna. Continued trawling may prevent the recolonisation of the benthic species — both sedentary and mobile forms. Trawling in previously untrawled areas has major effects on bottom flora and fauna in the trawl path, and continued trawling may affect susceptible species regionally.

Analysis and interpretation

The effects of trawling are related to type of gear used (some types cause less bottom damage), frequency of trawl passes over a particular location, sensitivity of the flora and fauna to trawl damage, ability to recolonise and regrow quickly, and the regional distribution of potentially affected species. There is little available information about the colonisation, growth and regional distribution of most species likely to be affected by trawling. Therefore, this indicator should be used to track the intensity of trawling in particular locations as a measure of pressure from trawling in those fishing grounds. Changes in trawling that indicate a broader geographic spread would probably be seen to be detrimental, although this conclusion might be modified by considerations of frequency and gear type, and the precise locations concerned. For example, if refuge areas were to be nominated in trawl grounds — in addition to the natural refuges that often exist (around untrawlable obstacles) — a broader geographic spread of trawl effort might be less destructive to the environment, depending on the nature of the potentially affected species.

Monitoring design and strategy

Data on this indicator would be captured by surveys of fishing management agencies at the State and Commonwealth level. The data sought would be, for each fishery, annual estimates of the area swept by each type of trawl gear, the location of trawl grounds, and the frequency distribution of trawling over a particular set of locations in each trawl ground. The frequency of trawling over particular places should be determined by establishing, from commercial fishing records, a random sampling of the number of trawl passes for grid locations in each trawling ground using the finest spatial scale of resolution available from GPS and vessel positioning systems.

Reporting scale

These data should be reported by fishery, by IMCRA subregions and by Marine Regions.

Outputs

The outputs should be maps showing areas trawled and, for each trawl ground, a graph of the distribution of trawling effort within the nominated ground. Where actual data on locations trawled are available, these should be shown as areas of different colour on the maps. The changes from year to year should be shown as maps and graphs.

Data sources

State and Commonwealth fishing agencies require fishing vessels to record the details of fishing effort, including the exact position of trawling. This information is typically aggregated in 6-minute grids for fisheries statistics, and would provide a suitable basis for data analysis.

Links to other indicators

This indicator is closely linked to indicator 4.3 fish stocks.

INDICATOR 4.6 FISHING GEAR

Description

This indicator covers the extent of fishing conducted by longline, drop line, gill net and meshing operations by fishery and by subregion and Marine Region, calculated as the number of day-km of fishing effort or, in the case of longlines, as the number of hooks deployed.

Rationale

Fishing and incidental capture of large fish and other animals may have an important and broad-scale effect on the top-level predators in marine and estuarine ecosystems — both those targeted and other species that may be ecologically dependant on them. The severity of the effect is probably related to both the intensity of fishing in a particular place and the nature of fish assemblages. Because of the way in which they are deployed, these forms of fishing gear are also susceptible to loss at sea but with fishing nonetheless continuing ("ghost fishing").

Analysis and interpretation

The effects of longlines, meshing, gill nets etc. on the regional distribution of larger fish taxa are poorly understood. However, it is clear that these fishing methods target the larger, more mobile species, and interpretation of changes in fishing effort is most likely to be relevant only on similarly large space and time scales. The information on fishing effort derived for individual fisheries is used to manage those taxa of direct management concern, usually the harvested species. However, a bycatch of a range of other species is common, including some protected species. The data on fishing effort gathered under this indicator will be most useful for consideration of the pressure on non-target taxa, and be best applied at the bioregional level.

Monitoring design and strategy

Data on this indicator would be captured by survey of fishing management agencies at the State and Commonwealth level. The data sought would be, for each fishery, annual estimates of the number of days fished for each type of gear, the location of fishing grounds, and the length (km) of gear or number of hooks set. If daily information is not available, then the finest temporal scale that is routinely recorded in each fishery should be adopted as the default time scale.

Reporting scale

These data should be reported by fishery, by IMCRA subregions and by Marine Regions.

Outputs

The outputs should be maps showing areas fished and, for each gear type, a graph of the distribution of day-km effort within the nominated ground. These should be summarised as areas of different colour on maps of the IMCRA regions and bioregions. The changes from year to year should be shown as maps and graphs.

Data sources

State and Commonwealth fishing agencies require fishing vessels to record details of fishing effort, including the exact position of longlines etc. This information is typically aggregated in 6-minute grids for fisheries statistics, and would provide a suitable basis for data analysis.

Links to other indicators

This indicator is closely linked to indicator 4.3 fish stocks, and to Biodiversity indicator 2.1.

Class 5: Non-renewable Products

These indicators document various aspects of the exploitation of minerals, oil and gas, sand and other non-living and non-renewable resources of estuaries and the sea. They are regarded as pressures on living components of estuarine and marine ecosystems.

Indicator 5.1 Ocean exploration

Description

This indicator documents the number of approval instruments (leases, permits, licences or approvals) issued for exploration as a measure of the mining exploration activity being undertaken in estuaries and bays, on the continental shelf and slope, and in the deep sea. It documents where each relevant type of exploration activity is undertaken, and the number, type, extent and relative intensity of each activity.

Rationale

Australia's continental shelfs and slopes are being increasingly explored in detail for oil and gas reservoirs. Also, gemstone dredging is becoming increasingly popular in nearshore regions adjacent to terrestrial gemstone mining areas. The exploration involved in these and other related industries, such as sand mining, may have local unacceptable impacts in marine systems, and their synergistic impacts may be important. This indicator also may be correlated with, and to some extent act as an early warning for, the implementation of actual mining operations.

Analysis and interpretation

As mining technology, market demand and our capacity to explore and mine in deeper waters develop, this indicator should be able to track the nature, location and scale of Australia's marine mining exploration activities. Although exploration activities in themselves may be a pressure on the ocean ecosystems, this indicator will, to some extent, also provide an early warning for areas that might be subject to future mining production activities. Baseline data are available from the relevant State and Commonwealth agencies.

Monitoring design and strategies

The data for this indicator should be gathered in consultation with the Commonwealth and State agencies responsible for authorising estuarine, bay and ocean exploration activities. These are typically the Commonwealth and State Mines and Energy portfolios, although EPAs and related authorities might also keep relevant data. The data sought from agencies would be, for each lease, permit, licence or approval issued for purposes that include exploration:

- industry type (oil/gas, minerals, sand, gemstones etc.);
- exploration activity/type (drilling, dredging, seismic, magnetic etc.);
- location and area covered (including boundary positions) of permit, licence or approval;
- number of exploration events to be undertaken; and
- expiry date for the permit, licence or approval issued.

This indicator should be assessed by survey of the relevant departments on an annual basis, and reported in each SoE cycle. It covers estuaries, intertidal regions, coastal waters, the EEZ and the offshore islands and dependencies.

Reporting scale

The data for each year should be summarised by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising changes in the number of approval instruments granted in each IMCRA subregion and Marine Region, the types of exploration activities undertaken, indicative locations of these activities, and the frequency of activities — all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown on maps summarising new areas being explored compared with the baseline of maps from the previous reporting cycle.

Data sources

Data are held by Commonwealth and State agencies responsible for managing mining and oil and gas activities — typically Mines and Energy portfolios.

Linkages to other indicators

This indicator is closely allied to indicator 5.2 ocean mining, which documents production activities.

Indicator 5.2 Ocean mining

Description

This indicator documents the number, location, type and intensity of ocean and estuary extraction activities for minerals, sand, oil and gas, and gemstones.

Rationale

Mining activities may place substantial pressure on various aspects of the ocean's ecosystems, its living resources and its biodiversity. Not all activities have the same type or extent of effect, and some have different effects depending on where they are conducted (in relation to the local flora and fauna). Monitoring of the location, extent and type of activities will assist in assessing how important those activities are in their effects on local environments and regional ecosystems. Where these activities are properly managed, the monitoring will demonstrate effective management and minimisation of potentially adverse effects that may be caused by the various extractive activities.

Analysis and interpretation

As mining technology, market demand and our capacity to explore and mine in deeper waters develop, this indicator should be able to track the nature, location and scale of Australia's marine and estuarine mining activities. It will provide a crude measure of the pressure applied to ocean ecosystems by various forms of mining activity. Baseline data are available from the relevant State and Commonwealth agencies.

Monitoring design and strategies

The data for this indicator should be gathered in consultation with the Commonwealth and State agencies responsible for managing estuarine, bay and ocean mining activities. These are typically the Commonwealth and State Mines and Energy portfolios, although EPAs and related authorities might also keep relevant data. The data sought from agencies would be, for each lease, permit, licence or approval issued for purposes that include commercial production:

- industry type (oil/gas, minerals, sand, gemstones etc.);
- extraction activity/type and number (drill hole, dredging etc.);
- location and area covered (including boundary positions) of lease, permit, licence or approval;
- product transportation (barge, pipeline, vessel etc.); and
- expiry date for the lease, permit, licence or approval issued.

This indicator should be assessed by survey of the relevant departments on an annual basis, and reported in each SoE cycle. It covers estuaries, intertidal regions, coastal waters, the EEZ and the offshore islands and dependencies.

Reporting scale

The data for each year should be summarised by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising the number of mining activities in each IMCRA subregion and Marine Region, the types of extraction activities undertaken with associated product transportation modes, indicative locations of these activities, and the frequency of activities — all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown on maps compared with the baseline of maps from the previous reporting cycle.

Data sources

Data are held by Commonwealth and State agencies responsible for managing mining and oil and gas activities — typically Mines and Energy portfolios.

Linkages to other indicators

This indicator is closely allied to indicator 5.1 ocean exploration.

Class 6: Water and Sediment Quality

These indicators document the levels of contaminants in the water, sediment and related aspects of marine and estuarine ecosystems; they are considered to be pressures on living components and biological processes of estuarine and marine ecosystems.

Indicator 6.1 Sediment quality (contaminants)

Description

This indicator documents the levels of, and changes in, the major contaminants of the surface sediments in estuaries, lagoons and bays, and continental shelfs of the mainland and offshore islands.

Rationale

Pollutants commonly accumulate in sediments, and measurement of sediment concentrations of contaminants is a useful way to track long-term trends in concentrations of most contaminants in marine and estuarine systems. These concentrations indicate the extent and magnitude of the pressure imposed by contaminants on the flora and fauna of the shallow-water ecosystems.

Analysis and interpretation

Many pollutants are synthetic chemicals (such as some pesticides) that do not normally exist in nature, while others are naturally occurring compounds or elements (such as hydrocarbons or trace metals) and become pollutants when they occur in higher than usual concentrations. Most find their way into the surface sediments of contaminated waterways after various periods (sometimes brief) in the water column. However, for both synthetic and natural materials, the precise level at which an effect can be expressed in the accompanying or adjacent biological systems is very difficult to define (see, for example, Suchanek 1994). So, rather than use concentration criteria to determine when levels are acceptable, we need to rely mainly on an assessment of trajectory to evaluate the level of stress imposed by contaminants. For synthetic chemicals, levels should be trending downwards, hopefully to near-zero, while for natural materials they should be close to natural background levels and not trending upwards. Locations that do not fit these objectives may be in most need of remedial action.

Change can only be detected against a baseline of existing or historic data, and then only with many caveats about collection and analysis techniques. Laboratory techniques have become increasingly sophisticated in the last decade, and data from earlier times are usually highly questionable. So full documentation of procedures, quality assurance and controls is critical if the currently collected data are to be useful in the next century. Many recent studies have gathered baseline data on contaminants in surface sediments, but most have been undertaken using different collection and analysis techniques and are very restricted in sampling scale and restricted to known or suspected local “hotspots”. Most such programs cannot provide a baseline for regional or national change in sediment contaminants.

Monitoring design and strategies

This indicator would be measured using traditional field sampling and laboratory analysis protocols to be defined and developed for a specific SOP. It would include analysis of major chemical constituents, nutrients, grain size and organic carbon. The indicator would be monitored annually (or as otherwise specified in the SOP) in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on the continental shelf. The monitoring would have three purposes: to track the global changes in contaminants that are probably influencing all Australia’s marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; and to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats.

Development of the detailed techniques for an SOP will need a specialised assessment and pilot study for each site and IMCRA subregion based on individual estuary catchments, and an analysis of existing data derived from previous major programs that have determined baseline levels of contaminants in sediments (such as the Department of Defence Jervis Bay Baseline Studies; CSIRO 1994). There is a range of overseas approaches to the sampling of sediments for long-term monitoring that should be reviewed to establish the precise SOP; these include studies such as Jones and Franklin (1997) and NOAA (1991).

Reporting scale

The data for each year should be summarised by reference site, by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each site, subregion and Marine Region together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising levels of each contaminant by site and subregion. Changes within and between SoE reporting cycles should be summarised by tables setting out the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion. These estimates of frequency of change should be aggregated from subregions to Marine Regions for reporting at the national scale.

Data sources

Commonwealth and State agencies responsible for managing coastal ecosystems — typically environment, conservation, water and fisheries portfolios — have data on contaminants in sediments. However, most relate to "hotspots" of concern, or are limited to small spatial areas, and have been gathered for issue-specific purposes. Realistic data on background concentrations over regional areas and decadal periods are not available.

Linkages to other indicators

This indicator is closely allied to indicator 4.4 seafood quality (contamination), indicator 6.2 sentinel accumulator program, and indicator 6.5 seabird eggs (contamination).

Indicator 6.2 Sentinel accumulator program

Description

This indicator documents levels of, and changes in, the major contaminants in biological sentinel accumulators in estuaries, lagoons and bays, and on continental shelfs of the mainland and offshore islands.

Rationale

Chemical residues and industrial chemicals are found in estuaries and bays near the major urban and industrial agglomerations, and potentially near regions of intensive agriculture. However, most marine and estuarine waters have low concentrations of these residues, and so measurements by traditional bulk water chemistry techniques are time consuming, laborious and expensive. Oysters, mussels and other taxa have been used to monitor the water column levels of many chemicals, and represent an early warning device to detect the spread of unpredicted residues into otherwise uncontaminated areas. Measurement of levels of contaminants in natural biological tissues is also a useful way to track long-term trends in levels of most contaminants in marine and estuarine systems, and complements measurements of total concentrations made in sediment systems.

Unlike sediments, living organisms "see" only the biologically available fractions of pollutants in waters and sediments. These may be dynamic (that is, pollutants may move from non-available to available fractions), and since we have only very limited understanding of how this process operates for most pollutants biological sentinel accumulators must be used to assess the extent to which total environmental levels of contaminants are biologically active. This is achieved by measuring their body burdens of the individual chemical residues. Overseas programs such as Mussel Watch have been used successfully to evaluate distribution and changes in pollutants (NOAA, 1986; O'Connor, 1992).

Analysis and interpretation

Many pollutants are synthetic chemicals (such as some pesticides) that do not normally exist in nature, while others are naturally occurring compounds or elements (such as hydrocarbons or trace metals) and become pollutants when they occur in higher than usual concentrations. However, as described under 6.1, for both synthetic and natural materials the precise level at which an effect can be expressed in the flora and fauna is difficult to define. So, rather than use concentration criteria to determine when levels are acceptable, we need to rely mainly on an assessment of trajectory to evaluate the level of stress imposed by contaminants. For synthetic chemicals, levels should be trending downwards, hopefully to near-zero, while for natural materials they should be close to natural background levels and not trending upwards. Locations that do not fit these objectives may be in most need of remedial action. Change can only be detected against a baseline of existing or historic data, and then only with many caveats about collection and analysis techniques. Laboratory techniques have become increasingly sophisticated in the last decade, and data from earlier times are usually highly questionable.

Full documentation of procedures, including collection strategy and techniques, and quality assurance and controls, is critical if the currently collected data are to be useful in the next century. Many recent studies have gathered baseline data on contaminants in selected biological materials, but most have been undertaken using different collection and analysis techniques, are very restricted in sampling scale and are restricted to known or suspected local "hotspots". Most such programs cannot provide a baseline for regional or national change in contaminants. However, recent studies in New South Wales (CSIRO 1994; Scanes 1995) were designed to establish baseline conditions for many contaminants — using seagrass leaves, oysters and mussels — in nearshore marine conditions.

Monitoring design and strategies

This indicator would be measured using refined field sampling and laboratory analysis protocols to be defined and developed for a specific SOP. It would probably be based on oysters, mussels and seagrass leaves, since there are existing baseline data on these taxa, they have overlapping distributions around the Australian coast, and they are widely and naturally available for field collection with minimum environmental impact. Alternative strategies, to be resolved in the development of an SOP, would be to use cultured species or synthetic chemical analogues deployed to monitoring sites for specified times. The indicator would be monitored annually (or as otherwise specified in the SOP) in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on the continental shelf. The monitoring would have three purposes: to track the global changes in contaminants that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; and to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats.

Development of the detailed techniques for an SOP will need a specialised assessment and pilot study for each site and IMCRA subregion based on individual estuary catchments and an analysis of existing data derived from previous major programs that have determined baseline levels of contaminants in relevant taxa (such as the Department of Defence Jervis Bay Baseline Studies; CSIRO 1994). The field collection of materials may be assisted by specially trained volunteers from community-based organisations such as marine naturalist and environmental groups.

Reporting scale

The data for each year should be summarised by reference site, by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each site, subregion and Marine Region together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising levels of each contaminant by site and subregion. Changes within and between SoE reporting cycles should be summarised by tables setting out the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion. These estimates of frequency of change should be aggregated from subregions to Marine Regions for reporting at the national scale.

Data sources

Commonwealth and State agencies responsible for managing coastal ecosystems — typically environment, conservation, water and fisheries portfolios — have data on contaminants in relevant taxa. However, most relate to "hotspots" of concern, or are limited to small spatial areas, and have been gathered for issue-specific purposes. Realistic data on background concentrations over regional areas and decadal periods are not available.

Linkages to other indicators

This indicator is closely allied to indicator 4.4 seafood quality (contamination), indicator 6.1 sediment quality (contamination), and indicator 6.5 seabird eggs (contamination).

Indicator 6.3 Turbidity

Description

This indicator documents the levels of, and changes in, turbidity in estuarine and coastal waters.

Rationale

Turbidity is an operationally determined parameter that is related to the "murkiness" of water. Depending on the instrument used, it is quantified by light either scattered from, or absorbed by, suspended particles and colloidal material, with perhaps minor contributions also from coloured dissolved organic matter (e.g. humic substances). Reasons for measuring turbidity differ slightly from those for other water quality indicators. Although increases in turbidity are often related to deterioration in water quality, it does not follow that the severity of the contamination can be assessed. For example, severe clouding of water by clay minerals and humic substances from soil disturbance may be unsightly, but not toxic to fish or other aquatic creatures. However, a lesser loading of metal-rich particles from mine tailings discharge, or high-clarity waters loaded with aluminium arising from runoff from acid sulphate soils, can devastate biota.

Measurements of turbidity are very useful when the extent of transmission of light through water is the information sought, as in the case of estimation of the light available to photosynthetic organisms. Another strong point in favour of turbidity is that field measurement is straightforward and can be performed rapidly by relatively unskilled monitoring teams. Turbidity is a measurement included in Waterwatch programs nationally. Because of the simplicity of the technique and its widespread use, large volumes of turbidity data are becoming available for national evaluation and interpretation. The turbidity of Australian coastal waters is an important issue in relation to benthic productivity, since many highly valued seagrass and algal bed communities have evolved in, and depend on, conditions of high light penetration (low turbidity).

Analysis and interpretation

High turbidity values are the data of interest, and change in waters from low to high values. A problem encountered is one shared with other water quality indicators — the need for national baseline data that make it possible to distinguish values and patterns that depart from the norm and may indicate environmental problems or anomalies.

It should be noted that converting turbidity to suspended solids concentration (a measurement that is often of interest to geochemists, sediment modellers and others) is not a simple matter. It is possible only if: the same instrument is used for all measurements (not just the same technique — nephelometry or transmissometry); the turbidimeter is calibrated with a turbidity standard and suspended matter from the waters to be monitored; and, very importantly, particle size and composition do not change over the monitoring period. Shifts in long-term patterns (in space and time) of turbidity in estuarine and coastal waters are of concern given the unique values of Australia's seagrass beds and algal assemblages, but these can only be determined by evaluation against a baseline of data. In general terms, a tendency to increasing turbidity, for longer periods or over greater areas, would usually be considered detrimental.

Monitoring design and strategies

Temporal scales: Like most other water quality indicators, turbidity is worth measuring over a wide range of time scales. Medium to long-term trends (monthly and longer) are to be favoured for national state of the environment reporting. Nevertheless, extremes resulting from floods or other exceptional events are important information in the Australian context because these events are responsible for most transport of suspended particulate matter to coastal waters.

Spatial scales: Turbidity values are often very low in marine waters. As a result, routine measurements of turbidity are often confined to rivers, streams and the upper reaches of estuaries (i.e. small spatial scales).

Survey strategy: Turbidity measurement is well suited to field surveys, for the reasons given above. Since most of the suspended particulate matter entering coastal waters has a terrestrial source (phytoplankton blooms arising from incursions of nutrient-enriched marine waters are an exception), estuaries are an appropriate monitoring location for land run-off. They act both as a filter and as a channelling conduit between land and sea, and are thus sensitive to change. A selection of estuaries that are regularly monitored around the nation, in a set of national reference sites, should be useful in assessing regional conditions. Choice of estuaries within regions could be on the basis of catchments characterised by different land-uses —urban/industrial, rural, mining/forest operations or undisturbed landforms (national parks, "old-growth" forest or similar).

A two-tiered monitoring scheme is proposed comprising: intermittent sampling together with other water quality indicators; and continuous sampling at a master station. Within each estuary, a sub-sampling approach could involve five sites sampled monthly. At each site, surface and bottom water samples would be collected and turbidity measured. It would also be advisable to pass a measured volume of water sample through a filter membrane (eg. 0.45 μm or 0.22 μm pore size) to obtain the concentration of suspended particulate matter gravimetrically (the relatively new technique of field flow fractionation should be considered in the longer term as it gains wider acceptance and a need for greater characterisation of suspended particulate matter is recognised).

Turbidity sensors are well suited to automated monitoring systems. One of the five stations involved in the intermittent estuarine sampling should also be identified as the "master" station, at which an automatic turbidity monitor (most likely coupled with automated measurement of temperature, conductivity and chlorophyll) is installed. It would sample continuously at the surface and near the bottom. Incorporation of this sampling program into existing estuarine surveys done by State agencies or other organisations would be advantageous. Turbidity is being evaluated as a parameter able to be measured by remote sensing; such an approach would have obvious appeal for SoE reporting and, supported by selective ground-truthing like that described above, would be suitable for a national approach.

The detail of a monitoring program for SoE will need to be developed and defined in an appropriate SOP.

Reporting scale

This indicator should be reported at national, State and regional levels — with increased spatial and temporal resolution in that order. At the national level, annual reporting will be made from monthly measurements (or from monthly consolidated statistics from the automatic turbidity station) in specified key estuaries and coastal waterbodies. Additional sites could be reported from approved monitoring by State and local governments and community groups.

Data sources

Doubtless, large amounts of data exist for estuaries and coastal waters around Australia (collected by State agencies, local government, community groups and environmental consultants), because turbidity assessment is a routine and simple measurement. However, because the data would have been obtained with a variety of instruments using different techniques, and in different states of calibration, it could be difficult to validly compare historical data. Standardised methods need to be developed and disseminated widely to groups doing turbidity measurements in the field. The possibility of making turbidity measurements via remote sensing needs to be assessed as a means of obtaining data frequently and synoptically over a broad region.

Outputs

National reporting of turbidity is probably most easily achieved using maps displaying the numbers of estuaries and other inshore waterbodies in different classes of annual median turbidity concentration. At the IMCRA subregion scale, the data may be best displayed using maps showing actual classes of annual median turbidity level in each waterbody. Sufficient baseline data exist to establish a range of classes. Tabulation of peak values associated with floods and other events that cause mass transport of sediments would also be valuable, if these can be estimated using remote sensing or another cost-effective approach. Once sufficient SoE information is available, it will be possible to include annotated tables on the maps summarising trends for the indicator and showing the statistical significance of the trends. These trends should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Linkages to other indicators

For effective use of the turbidity indicator, survey measurements should be made and reported with other water quality indicators — in particular, 6.1 sediment quality (contaminants), 6.4 water nutrients (nitrogen), and 3.17 chlorophyll — and evaluated in combination with most of the Habitat Quality indicators (3.1–3.4, 3.6–3.8, 3.10–3.12 and 3.14–3.17). The human influence — both pressure and response indicators (mostly under Class 7: Integrated Management, 7.2, 7.3 and 7.5–7.7, but also 4.1 aquaculture effort and 5.2 ocean mining) — will be gauged in the long-term by changes in water quality, such as turbidity changes. Other more specific indicators for human pressure developed under the Land and Human Settlements themes, e.g. mining, sewage and stormwater, could also be relevant.

Indicator 6.4 Water nutrients (nitrogen)

Description

This indicator documents designated forms of nitrogen in estuarine and marine waters.

Rationale

Nitrogen is one of the main plant nutrients, and in marine systems it is most often the limiting nutrient — the one whose concentration governs the viability and growth of plant species. (This contrasts with freshwater systems where phosphorus is often the limiting nutrient.) Abundant and bioavailable nitrogen, combined with other favourable conditions, can lead to eutrophication of waterways — in extreme situations familiar to most Australians in the graphic choking of coastal lagoons, estuaries and other confined marine systems by excessive growth of algae. In less severe circumstances, excess levels of nitrogen cause initially subtle but eventually chronic changes to marine ecosystem structure. Sediments can often serve as a reservoir for nutrients that regularly recharge overlying waters, and thus serve to trigger a perennial cycle of algal blooms. Hence, this indicator should portend, or identify the potential for, eutrophication and problem algal blooms in marine waterways.

Analysis and interpretation

Concentrations of nitrogen species should initially be compared with regional baseline levels for the nutrient. Here we are taking baseline to mean existing data obtained from marine waters unperturbed by human activities, and presumably representative of historical natural conditions. The Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992) provided some data for baseline nutrient levels for a few Australian coastal waters. These would need to be developed further, to provide a comprehensive nutrient index for all coastal waters and to have the potential to be extended to estuaries. In the current revision of the ANZECC guidelines one proposition is to include a "trigger" concentration for individual nutrient species on a bioregional basis. This trigger concentration is the level below which adverse effects have not been reported. In making the comparison between observed and baseline nitrogen concentrations, an estimate of nutrient status might be made. "Snapshot" observations of nitrogen concentrations may not be typical; interpretations should be made cautiously, mindful of other environmental conditions and the possibility of missing short-term fluctuations (i.e. aliasing of data). Moreover, nutrient data must be used in concert with biological indicators to obtain a complete picture of impending problems for waterway management.

Initially, nitrogen concentrations should be the basis for the indicator, but the longer- term aim should be to obtain both concentrations observed in, and the nitrogen loading (typically tonnes per annum) to, marine and estuarine waterbodies. The latter is perhaps a better Pressure indicator, but is more demanding to gather because it requires both nutrient concentrations and associated flow measurements.

Monitoring design and strategies

Temporal scales: Nutrient levels respond to change on a very broad range of scales, from perhaps minutes as a flash flood sweeps sediments and wastes into an urban stream, to seasonal as a result of cycles of planktonic growth and decay, and out to decadal as changes in land use are reflected in coastal ecosystems (mangroves, reefs, seagrass beds etc.). Therefore, surveys need to be conducted at different scales. Nationally, it is perhaps relevant to gather data at annual to interannual intervals to monitor long-term trends (but monthly time-series measurements are probably required at Commonwealth-sponsored facilities to effectively resolve these time scales). Nevertheless, it is fundamental that State and regional agencies are exhorted to monitor at much shorter time-scales for effective management of marine systems. It would prove useful to extract from the data statistics that describe variability (e.g. means, extremes, event-related levels etc.). Automated field instrumentation will become increasingly important for local high-frequency monitoring of nutrients.

Spatial scales: Nutrients are typically measured at scales from estuary-wide in surveys in coastal regions to broad expanses of ocean (104–105 km^2) in offshore research voyages. Individual stations in key locations, when monitored over time, can give valuable insight into nutrient levels. Examples of this approach are the CSIRO coastal station network, and international time-series stations in the Atlantic and Pacific Oceans.

Survey strategy: The form of nitrogen is important in determining its availability for biological uptake. Although total nitrogen may be an important measurement itself (especially if the organic nitrogen or particulate nitrogen fractions are sizeable), it must be supplemented by the dissolved inorganic forms, ammonia, nitrite and nitrate, which are known to be readily available to biota.

Since most of the increase in nutrients entering coastal waters is the result of terrestrial activities, estuaries are an appropriate monitoring location for land run-off. They act both as a filter and as a channelling conduit between land and sea, and are thus sensitive to change. A selection of estuaries that are regularly monitored around the nation, in a set of national reference sites, should be useful in assessing regional conditions. Choice of estuaries within regions could be on the basis of catchments characterised by different land uses — urban/industrial, rural, mining/forest operations or undisturbed landforms (national parks, "old-growth" forest or similar). Within each estuary, a sub-sampling approach could involve five sites sampled monthly. At each site, surface and bottom water samples would be collected, and analysed for different forms of nitrogen (dissolved and particulate). Collection of surface sediment samples should also be considered. Incorporation of this sampling program into existing estuarine surveys done by State agencies or other organisations would be advantageous.

With automated nutrient analysers for field measurement just gaining acceptance, it would be strongly advisable to consider the incorporation of this type of instrument, when proven, into the survey design to give continuous monitoring at one of the five estuarine stations (as described in the *Survey strategy* for indicators 3.17 chlorophyll concentrations and 6.3 turbidity). Short-term nutrient fluctuations — missed with intermittent sampling — would then be observed.

Atmospheric and groundwater transport of nutrients can bypass estuaries; the significance of this under Australian conditions needs to be assessed.

The detail of a monitoring program for SoE will need to be developed and defined in an appropriate SOP.

Reporting scale

The indicator should be reported at national, State and regional levels, with increased spatial and temporal resolution in that order. At the national level, annual reporting will be made from monthly measurements in specified key estuaries and coastal waterbodies; additional sites could be reported from approved monitoring by State and local governments.

Outputs

Nitrogen species for reporting include ammonia, nitrate and nitrate (these two could be reported together as oxyanions of nitrogen, NOx), and total nitrogen (both filtered and unfiltered). These data would be compared with the "trigger" concentrations mooted in the revised ANZECC Water Quality Guidelines, becoming a set of threshold levels. At the estuary scale, waterbodies that exceed the ANZECC threshold level will be identified in map form with annotated tables of data showing monthly mean concentrations. At the IMCRA subregion scale, the data may be best displayed using maps showing actual classes of monthly mean nitrogen concentrations for each form of nitrogen in each waterbody. Sufficient baseline data exist to establish a range of classes. Tabulation of peak values associated with floods and other events that cause mass transport of sediments would also be valuable. At the national scale, numbers and locations of estuaries and coastal waterbodies that exceeded the ANZECC trigger criteria would be mapped, together with the distribution of waterbodies in the various classes for each form of nitrogen. Once sufficient SoE information on nitrogen is available, it will be possible to include annotated tables on the maps summarising trends for the indicator and showing the statistical significance of the trends. These trends should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Data sources

In a review of existing nutrient data, Brodie (1995) noted that "few long-term records of nutrient (or phytoplankton) concentrations, taken on a regular basis at consistent sites in Australian coastal waters, are available". An exception is the CSIRO coastal station network, with some water quality records extending back 50 years; four stations remain operational out of a peak of 13 stations. State agencies are routinely monitoring some eutrophic and other important coastal waterbodies. A plethora of Environmental Impact Assessments and compliance monitoring measurements for water quality, including nutrients, is performed each year around the nation by local government, industry and environmental consultants. However, this work is often limited in scope, data integrity and availability. (Much of the older data is possibly of dubious quality. There is need for nutrient intercalibration exercises, and for standardisation of analytical methods — especially for estuarine waters.)

National data management for environmental quality is on the horizon; it is sorely needed for the effective gathering, integration, quality control and assurance, and security of data. A national database will facilitate a revision of Rochford's (1980) landmark paper on the nutrient status of the oceans around Australia, and enable a similar interpretative exercise on estuaries nationally.

Linkages to other indicators

It is advantageous to measure nitrogen species concentrations concurrently with other Water/Sediment Quality indicators — 6.1 sediment quality (contaminants) and 6.3 turbidity — and 3.17 chlorophyll concentrations in field surveys, and to integrate nitrogen with most of the Habitat Quality indicators (3.1–3.4, 3.6–3.8, 3.10–3.12 and 3.14–3.17) for further analysis of ecological effects. The human influence — both Pressure and Response indicators (mostly under Class 7: Integrated Management, 7.2, 7.3 and 7.5–7.7, but also 4.1 aquaculture effort — will be gauged in the long term by changes in water quality, such as nutrients. Other more specific indicators for human pressure developed under the Human Settlements theme, e.g. sewage and stormwater, could also be relevant.

Indicator 6.5 Seabird eggs (contamination)

Description

This indicator documents the levels of, and changes in, contaminants in the eggs of seabirds that use the estuaries, lagoons, bays and continental shelfs of the mainland and offshore islands. The target contaminants are industrial chemicals, pesticides and mercury.

Rationale

Chemical residues and industrial chemicals are found in estuaries and bays near the major urban and industrial agglomerations, and potentially near regions of intensive agriculture. However, most marine and estuarine waters have low concentrations of these residues, and so measurements by traditional bulk-water chemistry techniques are time consuming, laborious and expensive. Oysters, mussels and other taxa have been used to monitor the water column levels of many chemicals, and represent an early warning device to detect the spread of unpredicted residues into otherwise uncontaminated areas. Measurement of levels of contaminants in natural biological tissues is also a useful way to track long-term trends in levels of most contaminants in marine and estuarine systems, and complements measurements of total concentrations made in sediment systems. Unlike sediments, living organisms "see" only the biologically available fraction of pollutants in waters and sediments. This may be dynamic; that is, pollutants may move from non-available to available fractions.

Since we have only a very limited understanding of how this process operates for most pollutants, biological sentinel accumulators such as seabirds must be used to assess the extent to which total environmental levels of contaminants are biologically active. This is achieved by examination of their body burdens of the individual chemical residues. In the case of seabirds, the most efficient way to track exposure to lipophilic (fat-loving) residues such as pesticides is by analysis of the concentrations of these chemicals in their eggs. Overseas studies have found this a useful way to determine and monitor pesticide exposure in seabirds with minimum invasion of, and impacts on, populations (Coulson *et al.* 1972; Barrett *et al.* 1985; Wilson and Earley 1986; Stronkhorst *et al.* 1993). Also, fish-eating marine birds (shags) may accumulate, in their eggs, pesticides not accumulated by mussels (Allen and Thompson 1996). Using eggs of seabirds as a monitoring tool has a number of advantages: the readings represent actual exposure of a top predator to the target contaminants; the eggs have a known affinity for pesticides and mercury; the eggs are easy to sample and analyse; and the sampling has a limited ecological impact on the bird population (Becker 1989).

Analysis and interpretation

There have been few studies of contaminants of seabird eggs in the Australian environment. So, rather than use concentration criteria to determine when levels are acceptable, we need to rely mainly on an assessment of trajectory to evaluate the level of stress imposed by contaminants. For synthetic chemicals, levels should be trending downwards, hopefully to near-zero, while for natural materials such as mercury they should be close to natural background levels and not trending upwards. Locations that do not fit these objectives may be in most need of remedial action. Change can only be detected against a baseline of existing or historical data, and this will be developed in the context of a standard SOP for this indicator.

Monitoring design and strategies

This indicator would be measured using traditional field sampling and laboratory analysis protocols to be defined and developed for a specific SOP. It would probably be based on the eggs of silver gulls, a ubiquitous species whose populations will not be affected by egg collection. An additional group that could be investigated as a potential indicator group is the cormorants (shags). The indicator would be monitored annually, or as otherwise specified in the SOP, in a small number of carefully selected refuge/reference areas (possibly nature reserves/marine parks) and other randomly and explicitly selected sites in estuaries, lagoons and bays and on the continental shelf. The monitoring would have three purposes: to track the global changes in contaminants that are probably influencing all Australia's marine and estuarine ecosystems; to provide the basis for control/reference conditions so that local-scale effects of pollution can be determined more robustly; and to enable rehabilitation programs to have a relatively undisturbed condition as a target for the restoration of degraded habitats. Development of the detailed techniques for an SOP will need a specialised assessment and pilot study for each site and IMCRA subregion based on individual estuary catchments and an analysis of existing data derived from any previous sampling of seabird eggs. There does not appear to be a major baseline of Australian data on contaminants in seabird eggs (no references were found in the open scientific literature).

Reporting scale

The data for each year should be summarised by reference site, by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each site, subregion and Marine Region together with estimates of uncertainty (say 95% confidence limits). The difference between these estimates and any previous (or baseline) estimates should then be expressed as an estimate of change, together with an estimate of the size of change that could be statistically detected with the methods used.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising levels of each contaminant by site and subregion. Changes within and between SoE reporting cycles should be summarised in tables setting out the percentages of significant change (positive or negative change of statistical significance), preferably as a cumulative frequency distribution based on the data for each subregion. These estimates of frequency of change should be aggregated from subregions to Marine Regions for reporting at the national scale.

Data sources

There appear to be no Australian data sources.

Linkages to other indicators

This indicator is closely allied to indicator 4.4 seafood quality (contamination), indicator 6.1 sediment quality (contamination), and indicator 6.2 sentinel accumulator program.

Class 7: Integrated Management

These indicators measure aspects of our efforts to integrate the management of factors that affect the condition of our estuarine and marine ecosystems in order to achieve equity, both within and between generations, in the conservation and use of living and non-living resources.

Indicator 7.1 Beach stabilisation

Description

This indicator documents the nature and cost of beach rehabilitation and stabilisation works in estuaries, lagoons and bays, and on the open coast.

Rationale

The natural dynamic nature of beaches, changing climate and sea levels, and increasing use of the coastal zone for urban and recreational development have resulted in beach erosion becoming a critical problem for some local and State government authorities. Typical engineering responses — such as groynes, or sea walls — may have considerable impact on various values of beaches including their recreational amenity and biodiversity values. Beach stabilisation may change the nature of sediments in the adjacent waters and interrupt normal sand dynamics. This indicator, to monitor the effort needed to stabilise beaches and associated coastal areas against the effects of coastal/beach erosion, will be a measure of the number of groynes, walls and ramparts, and the number and size of beach nourishment programs.

Analysis and interpretation

As beaches and their environs become more urbanised or used for recreation, and with increasing sea level, impacts on human structures of extreme events such as storms, tide surges and cyclones will be increasingly felt. This indicator documents our responses to these pressures in the form of engineered structures. Baseline data are available from the local government, State and Commonwealth agencies that are responsible for managing coasts.

Monitoring design and strategies

This indicator documents activity in the design, implementation and maintenance of structures and efforts used in beach stabilisation — specifically:

- number and dollar costs of groynes, walls, and ramparts; and
- number and size ($) of beach nourishment programs.

These data should be recorded per km of coastline length within each IMCRA subregion. They should be gathered by survey of the relevant local and State government agencies on an annual basis, and reported in each SoE cycle. The indicator covers estuaries, lagoons, bays, coastal waters and the offshore islands and dependencies.

Reporting scale

The data for each year should be summarised by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps annotated with tables summarising the number of structures and beach nourishment programs in each IMCRA subregion and Marine Region and the associated dollar costs, all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown on maps, giving comparisons with the baseline of maps from the previous reporting cycle.

Data sources

Local government and State agencies responsible for managing beaches and coasts have reliable baseline data on the costs of these activities.

Linkages to other indicators

This indicator is closely allied to indicator 8.1 sea level.

Indicator 7.2 Catchment development

Description

This indicator documents the nature and types of land uses in the coastal river and stream catchments for estuaries, lagoons and bays.

Rationale

A major factor controlling water and sediment quality in coastal lagoons, bays and estuaries is land-based runoff and river conditions. Runoff, its composition and its duration and frequency are related to the types of land use distributed through the catchment. This indicator is designed to monitor changes in land use patterns (in broad categories) in each of the coastal river/estuary catchments that may affect the biological condition of estuarine ecosystems.

This indicator is being developed as part of the Land theme (Land indicator 2.3). For details refer to Hamblin (1998).

Indicator 7.3 Catchment management programs

Description

This indicator documents the number and nature of formally implemented catchment management programs covering coastal river and stream catchments.

Rationale

A major factor controlling water and sediment quality in coastal lagoons, bays and estuaries is land-based runoff and river conditions. Runoff, its composition and its duration and frequency are related to the types of land use that are distributed through the catchment. This indicator is designed to document the implementation of formally designed catchment management programs.

This indicator is being developed as part of the Inland Waters theme. For details refer to Fairweather and Napier (1998).

Indicator 7.4 Coastal care community groups

Description

This indicator documents the number of Coastcare and allied groups, the number of members in each group and the dollar costs of programs administered by them in each estuary, IMCRA subregion and Marine Region.

Rationale

Coastcare is a popular grass-roots national movement for organising activities and action on coastal issues A number of allied groups — such as Streamwatch, Waterwatch, those involved with the Fisheries Action Program etc. — also undertake activities related to protection of aquatic habitats in catchments and beaches, and in relation to fish. The participation of citizens in these groups is a measure of their awareness and concern about local coastal issues.

Analysis and interpretation

This indicator documents our responses to the increasing awareness of coastal issues and concern about the impacts of those issues on human populations and the environment. It will reflect increasing efforts by governments to involve local communities in coordinated local action to address key coastal issues. Baseline data are available from the local government, State and Commonwealth agencies responsible for managing some of the care groups

Monitoring design and strategies

The data for this indicator will be collected by survey of State and national government agencies, seeking information on:

- the number of Coastcare and allied groups;
- the geographical area of coverage;
- the number of people involved; and
- dollars spent annually.

This indicator should be assessed by survey of the relevant agencies on an annual basis, and reported in each SoE cycle. It covers estuaries, lagoons, bays, coasts and the offshore islands and dependencies.

Reporting scale

The data for each year should be summarised by estuary, by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each estuary, subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps of coverage by groups, annotated with tables summarising the number of groups and members in each estuary, IMCRA subregion and Marine Region and the associated dollar costs, all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown on maps giving comparisons with the baseline of maps from the previous reporting cycle.

Data sources

Local government and State agencies responsible for managing beaches and coasts have a reliable baseline of data on these groups and their expenditures. The number of members obviously fluctuates from time to time, as does the number of active members, and there are few baseline data.

Linkages to other indicators

Nil.

INDICATOR 7.5 COASTAL DISCHARGES

Description

This indicator documents the locations and number of licensed point-source discharges into estuaries, lagoons, bays and coastal waters, including the type and volume of materials discharged.

Rationale

Coastal discharges are responsible for the input of large volumes of wastewater, some of which contains pollutants of various types, to coastal systems. These discharges include sewage outfalls, urban stormwater drains and industrial outfalls. This indicator will document their location and the type of wastewater discharge, and estimate the volumes/loads of materials discharged.

Analysis and interpretation

This indicator documents the outfalls, and will track changes in their number, type and location. Information to be sought from the agencies, for each point-source outfall or discharge, is:

- location;
- type of material discharged; and
- estimates of annual loads and/or volumes.

Baseline data are available from the local government, State and Commonwealth agencies responsible for managing discharges — mainly Environment Protection Agencies. For some types of pollutants, national-scale data will be available under the National Pollutant Inventory.

Monitoring design and strategies

The data for this indicator will be compiled by survey of local and State government agencies, and will include data on non-compliance and accidental discharges, and stormwater discharges. The locations will be compiled by estuary, by IMCRA subregion and by Marine Region for national reporting.

This indicator should be assessed by survey of the relevant agencies on an annual basis, and reported in each SoE cycle. It covers estuaries, lagoons, bays, coasts, and the offshore islands and dependencies.

These data will be compared with data on comparable pollutant classes derived from the National Pollutant Inventory.

Reporting scale

The data for each year should be summarised by estuary, by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each estuary, subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps, annotated with tables summarising the number of discharges by major type and their aggregated loads/volumes of discharged materials in each estuary, IMCRA subregion and Marine Region — all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown on maps giving comparisons with the baseline of maps from the previous reporting cycle.

Data sources

Local government and State agencies responsible for managing sewage and urban stormwater have a reliable baseline of data.

Linkages to other indicators

This indicator is linked to various indicators in Habitat Quality, to indicator 6.1 sediment quality (contaminants), to indicator 4.4 seafood quality (contamination), and to indicator 6.5 seabird eggs (contamination).

INDICATOR 7.6 COASTAL POPULATION

Description

This indicator documents the locations and numbers of people in coastal cities, towns and agricultural regions, and shifts in populations, based on ABS census boundaries.

Rationale

Many of the factors that degrade marine and estuarine environments are related, and may be directly proportional, to the size of the local resident (and transient) human population. Such factors as housing, roads, urban infrastructure, recreation and tourism all can be related to degradation of estuaries and coastal marine habitats, even though many of the direct effects can be controlled and reduced using modern technology and management strategies.

This indicator is being developed as part of the Human Settlements theme. For details refer to Newton *et al.* (in prep.).

INDICATOR 7.7 COASTAL TOURISM

Description

This indicator documents the annual number of tourists undertaking local (day trips) and extended (overnight) trips within each estuary, IMCRA subregion, and Marine Region.

Rationale

Tourism is set to dramatically expand in coastal areas, according to various assessments of marine-dependent industries (such as AMISC 1997). This will have two components — the local (day-travel) tourists and those from more distant ports, including overseas. The provision of tourist facilities and infrastructure is potentially a major pressure on coastal environments, both in the sense of providing for accommodation and transport facilities and in direct effects such as recreational trampling or over-exploitation of valued species.

This indicator is being developed as part of the Human Settlements theme. For details refer to Newton *et al.* (in prep.).

INDICATOR 7.8 FISHING EFFECTS ON NON-TARGET BIODIVERSITY

Description

This indicator documents the number of fisheries management plans (State and Commonwealth) that contain effective indicators for monitoring the level of, and extent of reduction in, impacts on non-target organisms, and the number of such indicators.

Rationale

Fishing has a broad range of effects on marine and estuarine ecosystems, including: direct effects such as reductions in population sizes and shifts in the population structure of target species; effects on ecosystems caused by the removal of large numbers of top-level predators; the removal on non-target species as bycatch; damage to habitats caused by the operational use of fishing gear; and the effects of "ghost fishing" by discarded fishing gear (UNEP 1995). In the implementation of Ecologically Sustainable Development, fisheries management plans need to recognise effects on non-target organisms, and biodiversity generally, as potential constraints to fisheries production. The specific effects of fishing range from the impacts of non-selective bottom trawls (as used in some fish and prawn fisheries) on non-target organisms in the trawl path (Hutchings 1990) to accidental catch of seabirds on baited hooks deployed on longlines. Some of these impacts may be substantial and important for the populations of non-target organisms.

In response to information that fisheries may be adversely affecting the environment or other species, fisheries management plans will need to adopt procedures to avoid or ameliorate these unintended effects. To assess the effectiveness of the plans, procedures and actions implemented in each fishery, the fisheries management plans will need to devise and incorporate indicators that measure the effectiveness of the measures introduced to assess and, where necessary, reduce undesirable unintended consequences of fishing activities. The extent to which these indicators are devised and implemented effectively is a measure of the concern of the fishing industry about these impacts, and of the response to pressures for reform.

Analysis and interpretation

This indicator will track progress towards comprehensive reporting on the unintended consequences of fishing activities, and the implementation of corrective measures where needed in individual fisheries. The effectiveness of the indicators used in each fisheries management plan will need to be independently established and evaluated. The indicators used in the fisheries management plans may include both direct and indirect measures of the effects on non-target biodiversity — for example, fishery-independent mapping and inventories of epibenthic fauna in trawl grounds (a direct measure), and quantities of trawl bycatch (an indirect measure).

Baseline data are available from the relevant State and Commonwealth fisheries management agencies, and are generally found in the individual fishery management plans.

Monitoring design and strategies

The data on this indicator will be gathered by annual survey and assessment of management plans for all defined fisheries (State and Commonwealth) to determine:

- whether appropriate indicators of the biodiversity of non-target organisms are included and monitored in and near fishing grounds; and
- the extent to which these data are used, where necessary, to revise management plans and actions to reduce the impact of fishing on non-target biodiversity.

The data to be captured for each fishery are:

- the number and types of indicators used to assess the level of impact on non-target biodiversity; and
- data on each indicator.

The data for this indicator will be compiled by fishery, by IMCRA subregion and by Marine Region for national reporting where the fishery covers an area smaller than the subregion or region.

Reporting scale

The data for each year should be summarised by fishery, by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each fishery, subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps, annotated with tables summarising the number of management plans with relevant indicators, for each IMCRA subregion and Marine Region — all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown on maps giving comparisons with the baseline of maps from the previous reporting cycle.

Data sources

Commonwealth and State agencies responsible for managing fisheries have a reliable baseline of data.

Linkages to other indicators

This indicator is linked to various indicators in Habitat Quality, to indicator 4.3 fish catch, and to indicator 4.5 trawl fishing area.

INDICATOR 7.9 GREAT BARRIER REEF MANAGEMENT

Description

This indicator documents the annual allocation of funds from government sources to the Great Barrier Reef Marine Park Authority (GBRMPA) and the Queensland Department of Environment for management of the Great Barrier Reef (GBR), and to Australian scientific institutions for research on the GBR.

Rationale

The GBR is Australia's only example of a major part of the marine realm that is managed in an integrated manner for multiple uses including conservation. The success of management can be ascribed to the scientific, legislative, institutional and funding framework within which the GBR is managed. As Australia's only example of integrated multiple-use management on a regional scale, it needs to be tracked; lessons, both good and bad, should be documented and promulgated. In future, other marine areas may also be managed in an integrated manner — benefiting from the lessons learnt in the management of the GBR. Many of the management decisions are based on scientific data and research findings. Some of the research is funded by a levy on tourists using the marine park. As a surrogate for the effort devoted to management of the GBR, the annual allocation of government funds to GBRMPA and the Queensland Department of the Environment for management purposes, and to scientific research conducted on the GBR, is monitored in this indicator. Funds raised from the tourism levy and used for research and management are also documented.

Analysis and interpretation

This indicator will track government and tourism derived funds allocated to management of the GBR. The success of the management efforts can be evaluated by analysis of the data reported in a range of Habitat Quality indicators that apply to the GBR and its IMCRA subregions.

Baseline data are available from GBRMPA, from the Queensland Department of the Environment, and from Australian universities.

Monitoring design and strategies

The data on this indicator will be gathered by annual survey of the relevant universities, and by analysis of the Annual Reports of the relevant government agencies.

Reporting scale

The data for each year should be summarised by IMCRA subregion where feasible, and by the whole GBR to comprise the national report. The year-to-year changes should be recorded for each subregion where feasible, and for the whole GBR.

Outputs

The outputs should be presented in the form of graphs of expenditure (or allocations) for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown by comparison with a time-series of data on the graphs.

Data sources

GBRMPA and the Queensland Department of the Environment have a reliable baseline of data, but historical university data may be more difficult to extract from overall university allocations.

Linkages to other indicators

This indicator is linked to various indicators in Habitat Quality.

Indicator 7.10 Integration of management

Description

This indicator documents the number of regions covered by an effective integrated ecosystem management framework that includes environmental performance indicators for assessing and reporting on ecosystem attributes related to the various responsibilities of the three levels of government and the activities of the private sector.

Rationale

In the implementation of Ecologically Sustainable Development and the *National Strategy for the Conservation of Australia's Biological Diversity* — and to meet new obligations for integrated management of ocean ecosystems under the developing Oceans Policy — management frameworks will need to be adopted and implemented that encourage integration of sectoral activities and specifically address system-level objectives, as opposed to objectives for each sector. The lack of integrated management of the full range of human activities and effects in marine and estuarine ecosystems, and the absence of an explicit, clear and accepted framework within which this can proceed, are frequently cited as the major impediments to the long-term maintenance and sustainable use of Australia's marine and estuarine living and non-living resources and biodiversity. Progress towards such a framework, and then effective implementation, is a key indicator of our willingness and capacity to manage marine systems effectively.

A major weakness in the present sectoral approach to managing human activities is the lack of hierarchically-organised systems performance indicators for the ecosystems of concern. Hence, an integrated approach to managing activities in these ecosystems will require the development and implementation of ecologically sound systems-level environmental indicators for the ecosystem. This indicator will track the development and implementation of such indicators at each level of organisation on a region-by-region basis, in the context of an overall integrative national framework.

Analysis and interpretation

This indicator will track progress towards a comprehensive and integrated approach to oceans and estuarine management. It is based on the assumption that oceans management will proceed on a hierarchical and regional basis, but within an overall national management framework. The objectives and environmental performance indicators will be assessed for relevance to the overall ecosystems of the region and subregions concerned. Sectoral objectives and indicators will only comply if they cover the region as a whole and relate to system-level attributes. (Such objectives would include assessment of change in regional biodiversity, but not the minimisation of bycatch in fisheries despite this being an important sector management objective with bycatch a pressure on regional biodiversity.)

Monitoring design and strategies

The data on this indicator will be gathered by annual survey and assessment of management plans for all IMCRA subregions to determine whether appropriate region-wide management plans are in place to integrate the activities of the main industry sectors that operate in each subregion. Appropriate management plans will be those that include system-level and system-scale ecological indicators, implemented according to nationally accredited standards and in accordance with an explicit and promulgated SOP for hierarchical regional integration of management.

The data for this indicator will be compiled by IMCRA subregion or by Marine Region for national reporting, depending on whether the management plan covers an area smaller than the subregion or region.

Reporting scale

The data for each year should be summarised by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded for each subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps, annotated with tables summarising the number of management plans with relevant indicators, for each IMCRA subregion and Marine Region — all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown on maps giving comparisons with the baseline of maps from the previous reporting cycle.

Data sources

Commonwealth and State sectoral agencies responsible for activities in marine systems have a reliable baseline of data. This will include objectives and indicators in management plans, and strategies and actions in the following sectors: fishing, oil and gas, mining, water and sewerage, tourism, conservation, and defence.

Linkages to other indicators

This indicator is linked to various indicators in Habitat Quality, and to Indicator 7.8 Fishing effects on non-target biodiversity.

Indicator 7.11 Marine network participation

Description

This indicator documents the participation (number on mailing list) in the Marine and Coastal Community Network (MCCN) by IMCRA subregion and Marine Region.

Rationale

The Marine and Coastal Community Network (MCCN) is sponsored by Environment Australia. It is a national network independent of government that maintains a marine and coastal awareness service by mailing regular newsletters and sponsoring various community-based meetings and activities. The main function of this popular and successful non-technical network is information exchange. The size of its mailing list is a measure of the interest shown by ordinary Australians in matters relating to coastal and marine management.

Analysis and interpretation

This indicator will track changes in public awareness. Changes in the number of people on the mailing list might be confounded by other factors — such as the growth of other information networks concerned with coastal matters, and the extent of government support for the MCCN. Nevertheless, monitoring of the numbers on the mailing list provides a useful Response Indicator to help gauge the depth of public interest and support for coastal issues.

Monitoring design and strategies

The data on this indicator will be gathered by annual assessment of the number of individual addresses on the MCCN mailing list in each postcode region, taken at a consistent time each year.

The data for this indicator will be aggregated by IMCRA coastal subregion and by Marine Region, then standardised to resident population for national reporting.

Reporting scale

The data for each year should be summarised by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded as graphs for each subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps, annotated with tables summarising the participation rate for each IMCRA subregion and Marine Region — all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown as graphs of annual data covering the whole period for which data are available (including the baseline data).

Data sources

The MCCN is the data source.

Linkages to other indicators

This indicator is linked to Indicator 7.13 Commonwealth Government marine management, to Indicator 7.4 Coastal care community groups, and to Indicator 7.16 State Government marine management.

Indicator 7.12 Marine protected areas

Description

This indicator documents the number, extent and classification of marine protected areas (classification based on IUCN (World Conservation Union) criteria), and other similar arrangements such as RAMSAR Sites and World Heritage Areas.

Rationale

Management of Australia's marine biodiversity involves securing a substantial (and representative) proportion in well-managed marine protected areas. These may fall into a range of levels of protection, but only those with a primary goal of nature conservation are considered to be marine protected areas. The IUCN has established a globally-accepted standard mechanism for evaluating and classifying nature reserves and conservations areas, and the IUCN categories and sub-categories will be used for this indicator. Although Australia has 261 marine protected areas, most are small and few are totally or primarily dedicated to the protection and preservation of species, genetic diversity, and ecosystem processes. Also, many regions have only very few, or very small, marine protected areas.

Analysis and interpretation

This indicator will track changes in the number and extent of, and level of protection afforded in, marine protected areas in Australia. A prime objective of the Commonwealth's Marine Protected Areas Program (formerly part of Ocean Rescue 2000) is the development and implementation of a national representative system of marine protected areas. This indicator will track progress towards implementation of that goal.

Monitoring design and strategies

The data on this indicator will be gathered by annual consultation with relevant agencies to establish, for estuaries and marine environments:

- the number of formally declared marine protected areas or other similar arrangements (such as RAMSAR Sites or World Heritage Sites) under either Commonwealth or State legislation;
- the area (km^2) in each of the seven relevant IUCN management objective categories and sub-categories within each marine protected area; and
- the existence and implementation of a plan of management for each marine protected area that includes regular monitoring of representative elements of biodiversity.

Reporting scale

The data for each year should be summarised by IMCRA subregion, and by Marine Region to comprise the national report. The year-to-year changes should be recorded as graphs for each subregion and Marine Region.

Outputs

The outputs should be presented in the form of maps, annotated with tables summarising the number and area of each marine protected area in each of the IUCN categories and the number of marine protected areas with implemented management plans that include biodiversity monitoring, for each IMCRA subregion and Marine Region — all shown for each year of the 4-5 year (or other SoE cycle) period being reported. Changes between reporting cycles should be shown as graphs of annual data covering the whole period for which data are available (including the baseline data).

Data sources

The data for this indicator are held by the environment or parks agencies in each State and the Northern Territory. For some classes of marine protected areas, the data will be held by fisheries agencies.

Linkages to other indicators

This indicator is linked to Indicator 7.13 Commonwealth Government marine management, and to Indicator 7.16 State Government marine management.

Indicator 7.13 Commonwealth Government marine management

Description

This indicator documents the annual expenditure of Commonwealth Government funds on national, regional and local-scale programs for coastal and marine management, including in the environment, conservation and resource sectors. It includes funds raised by government authorities in the form of levies and charges to offset changes in consolidated revenue outlays.

Rationale

Management of Australia's marine and estuarine ecosystems is, at present, largely a government responsibility undertaken on behalf of the Australian people. Although partnerships with the private sector will increase, government resources will still be needed to facilitate and supervise the process of ocean and estuarine conservation and management. This indicator is a large-scale measure of the level of concern felt in the public arena about the adequacy of existing coastal management arrangements, as interpreted and expressed in Commonwealth Government policy and programs.

Analysis and interpretation

This indicator will track changes in the funds committed (allocated) by the Commonwealth Government to improve integration and overall management of Australia's estuaries and oceans. It will monitor the Commonwealth Government's funding responses to concerns about coastal issues and management.

Monitoring design and strategies

The data on this indicator will be gathered by annual consultation with the relevant Commonwealth Government agencies to establish, for estuaries and marine environments, the number of government programs directed to estuaries, coastal issues or marine management, and the funds allocated to each. This includes funds allocated for the routine administration and operation of departments that have marine and estuarine responsibilities, apportioned pro rata as necessary.

Reporting scale

The data for each year should be summarised by program and/or department to comprise the national report.

Outputs

The outputs should be presented in the form of annual allocations as graphs for each program and/or department.

Data sources

The data for this indicator are held by the relevant Commonwealth Government agencies.

Linkages to other indicators

This indicator is linked to indicator 7.16 State Government marine management.

Indicator 7.14 Ship visits

Description

This indicator documents the frequency of ship visits to Australian ports by type of vessel, port of origin, and nature of cargo (imported or exported).

Rationale

Shipping carries with it a number of potential risks to the estuarine and ocean ecosystems. These include the risk of importation, and coastal translocation, of marine pests via ballast waters and hull fouling, the risk of oil spills and discharges from routine operations, and the risk of accidents involving toxic cargoes or bunker fuels. These risks are related to the frequency of traffic, the nature of the vessels, their cargoes and so on.

Analysis and interpretation

This indicator will track changes in shipping patterns to Australian ports. Frequency, type of vessel and type of cargo handled will act as a crude surrogate for the level of risk (pressure) that shipping operations might place on estuarine and ocean environments.

Monitoring design and strategies

The data on this indicator will be gathered by annual consultation with the Australian Maritime Safety Authority, to gather annual statistics on:

- the number of ships, including Australian coastal vessels, entering each declared port that receives ships from other countries;
- the nature of the vessels (broad class of vessel); and
- the type of cargo handled (in broad classes of cargo types).

Reporting scale

The data for this indicator should be captured for each recognised Australian port, no matter how large or small, that receives vessels from other countries.

Outputs

The outputs should be presented in the form of annual ship visits to the ports in each class of vessel and each class of cargo in each IMCRA subregion, and aggregated to Marine Regions for the national report. Year-to-year changes should be shown on graphs associated with each IMCRA subregion and Marine Region.

Data sources

The data for this indicator are held by the Australian Maritime Safety Authority.

Linkages to other indicators

This indicator is linked to indicator 7.15 shipping accidents, and to indicator 3.10 pest numbers.

Indicator 7.15 Shipping accidents

Description

This indicator documents the frequency of shipping accidents in Australian waters, together with the nature of the main cargo carried, materials lost to the environment, estimates of damage caused to the environment, and the number of ships inspected annually for safety compliance and problems consequently identified.

Rationale

Shipping carries with it a number of potential risks to the estuarine and ocean ecosystems. These include the risk of importation, and coastal translocation, of marine pests via ballast waters and hull fouling, the risk of oil spills and discharges from routine operations, and the risk of accidents involving toxic cargoes or bunker fuels. These risks are related to the frequency of traffic, the nature of the vessels, their cargoes and so on.. Shipping accidents range from minor groundings to major, highly visible and often locally catastrophic ship-to-ship collisions or major groundings. Repeated accidents may cause serious environmental problems, and even a single accident may have a major impact in a highly sensitive habitat or on a sensitive species.

Analysis and interpretation

This indicator will track the number, location and nature of shipping accidents in Australian waters, as a measure of the pressure imposed on the ecosystems near shipping lanes and near ports and harbours.

Monitoring design and strategies

The data on this indicator will be gathered by annual consultation with the Australian Maritime Safety Authority, to obtain annual statistics on:

- the number of shipping accidents, and their individual locations;
- the nature of the accidents (broad class of accidents);
- the type of vessel(s) involved (broad classes of vessels);
- the type of cargo carried (in broad classes of cargo types);
- estimates of materials lost to the environment;
- estimates of any conspicuous environmental damage caused;
- the number of ships inspected for safety; and
- the number and nature of problems detected during the inspections.

Reporting scale

The data for this indicator should be captured for each recognised and reported accident, no matter how large or small, anywhere in Australia's estuaries, coastal waters or EEZ.

Outputs

The outputs should be presented in the form of annual number of shipping accidents in each class of accident, class of vessel and class of cargo in each IMCRA subregion, and aggregated to Marine Regions for the national report. Estimates of materials lost to the environment through accidents should be summarised on an annual basis for each IMCRA subregion, and each Marine Region. Year-to-year changes should be shown on graphs associated with each IMCRA subregion and Marine Region.

Data sources

The data for this indicator are held by the Australian Maritime Safety Authority.

Linkages to other indicators

This indicator is linked to indicator 7.14 ship visits, and to various indicators in Habitat Quality.

Indicator 7.16 State Government marine management

Description

This indicator documents the annual expenditure of State and the Northern Territory funds on regional and local-scale programs for coastal and marine management, including in the environment, conservation and resource sectors. It includes funds raised by government authorities in the form of levies and charges to offset changes in consolidated revenue outlays.

Rationale

Management of Australia's marine and estuarine ecosystems is, at present, largely a government responsibility, undertaken on behalf of the Australian people. Although partnerships with the private sector will increase, government resources will still be needed to facilitate and supervise the process of ocean and estuarine conservation and management. This indicator is a large-scale measure of the level of concern felt in the public arena about the adequacy of existing coastal management arrangements, as interpreted and expressed in State-level government policy and programs.

Analysis and interpretation

This indicator will track changes in the funds committed (allocated) by the State-level governments to improve integration and overall management of Australia's estuaries and oceans. It will monitor the governments' funding responses to concerns about coastal issues and management.

Monitoring design and strategies

The data on this indicator will be gathered by annual consultation with the relevant government agencies to establish, for estuaries and marine environments, the number of government programs directed to estuaries, coastal issues or marine management, and the funds allocated to each. This includes funds allocated for the routine administration and operation of departments that have marine and estuarine responsibilities, apportioned pro rata as necessary.

Reporting scale

The data for each year should be summarised by program and/or department in each State and the Northern Territory to comprise the national report.

Outputs

The outputs should be presented in the form of annual allocations as graphs for each program and/or department.

Data sources

The data for this indicator are held by the relevant government agencies.

Linkages to other indicators

This indicator is linked to indicator 7.13 Commonwealth Government marine management.

Indicator 7.17 World Heritage Area tourism

This indicator documents the number of tourists visiting Australia's two marine World Heritage sites (Shark Bay and the Great Barrier Reef) and estimates of the annual tourism fees, levies and direct charges ($) contributed by users of the two sites. It may also be appropriate to track tourism at marine sites near other World Heritage sites (such as South West Tasmania).

World Heritage Areas are declared because they are globally exceptional places. Shark Bay and the Great Barrier Reef have major natural features that attract many tourists. This indicator is designed to track the extent of tourism pressure on these two areas, separate from that of coastal tourism generally, and the changes in dollar value that can be ascribed to use of these two outstanding natural locations.

This indicator is being developed as part of the Natural and Cultural Heritage theme (Pearson *et al,* in prep.).

Class 8: Ecosystem-level processes

These are broad-scale indicators that are, or are related to, various important functions or processes in marine and estuarine ecosystems. They also have an important role in interpreting trends that might be detected in the other indicators.

There are many ecosystem-level processes — physical, chemical or biological — that could be used as indicators. However, in broad terms, the relevance of changes in such processes to issues and elements of the environment is very difficult to evaluate. Our limited understanding of how marine and estuarine ecosystems function, or are controlled, means that there is a high risk that measurement of arbitrarily chosen ecosystem-level processes would not detect major signals from the environment about important changes. Most such processes, therefore, fail to meet the following indicator selection criteria:

- serve as a robust indicator of environmental change;
- provide an early warning of potential problems; and
- have relevance to policy and management needs.

As our understanding of marine and estuarine ecosystems advances, new models of ecosystem function will enable appropriate indicators to be chosen and interpreted for use in national SoE reporting. In selecting key indicators here, the emphasis has been placed on choosing ecosystem-level processes that are important for the interpretation of other key indicators, and placing them in broader context.

Indicator 8.1 Sea level

Description

This indicator documents the long-term sea level at the Australian coast and at offshore islands.

Rationale

Sea level is rising. The extent of the rise, and local variability in the rate of rise, are important issues in planning how to respond. Increasing sea levels may have important impacts on coastal habitats, particularly those such as algal beds and seagrasses that have depth-limited distributions related to light availability. However, intertidal assemblages on hard and soft substrates are also likely to be influenced by rising sea level as the area available for their habitat alters; this change will be related to local topography and human responses to sea level rise. Rising sea levels will also increase the risk to beaches and dunes from extreme climatic events, and increase risks to coastal roads, housing, ports etc. The way in which sea level interacts with climatic change is of critical importance.

Analysis and interpretation

This indicator will track changes in the sea level at a range of fixed locations along the coastline. These data can be used to construct empirical models to explain (and predict) various patterns that may be observed in the data gathered on other indicators. For example, mean sea level at Fremantle is used to predict lobster recruitment onto coastal reefs, and subsequently into the Western Australian lobster fishery. Other useful models may be constructed in relation to coastal erosion, seagrass loss etc..

A baseline of data has been captured by the National Tidal Facility.

Monitoring design and strategies

The data on this indicator will be gathered by annual consultation with the National Tidal Facility in Adelaide to establish sea level changes at each gauge location.

Reporting scale

The data for each year should be summarised by individual gauge, by IMCRA subregion and by Marine Region to form the national report.

Outputs

The data at each level may be most usefully summarised on a map as colour classes for rises and falls annually. Long-term changes for all years for which records exist should be summarised on a similar map showing the long-term rise for each IMCRA subregion, together with the variability surrounding each class.

Data sources

The data for this indicator are held by the National Tidal Facility in Adelaide.

Linkages to other indicators

This indicator is linked to many other indicators, particularly those associated with coastal dunes, beaches, and intertidal and shallow subtidal habitats.

Indicator 8.2 Sea surface temperature variability

Description

This indicator documents the annual variability of sea surface temperatures (SST) in all estuarine, coastal and offshore waters of the EEZ.

Rationale

As climate changes, or becomes more variable, the patterns of ocean currents may also alter. The changes could include shifts in the dominant currents. As a result, seasonal patterns of temperature variability could change, affecting the spawning, recruitment, growth and distribution of both economically important species and others. SST is also a useful surrogate for general current patterns, particularly when combined with ocean colour (chlorophyll). Future developments in satellite remote sensing, such as fine-scale sea level measurements, may also be able to show ocean current patterns and their variability.

Analysis and interpretation

This indicator will track broad-scale changes in SST. Its primary use will be to explore patterns in SST variability that may be related to patterns of variability in other indicators, particularly those describing the condition of habitats.

Monitoring design and strategies

The data on this indicator will be gathered by satellite remote sensing techniques. New satellite platforms will be able to supplement the existing ones to enhance the quality of available SST data. The development of a precise SST monitoring design will need to be the subject of a detailed separate SOP for national SoE reporting.

Reporting scale

Data should be captured and archived at the finest spatial scale available from the satellite platform. The data, probably for each month, will need to aggregated and summarised into, say, one-minute data for all areas within Australia's jurisdiction.

Outputs

The outputs should be presented in the form of annual maps of each IMCRA subregion and of Australia showing mean temperature and a measure of spatial and temporal variability, probably derived from the monthly aggregated data.

Data sources

The data for this indicator are purchased and archived by the CSIRO Earth Observation Centre in Hobart.

Linkages to other indicators

This indicator is linked to many others, particularly those associated with coastal dunes, beaches and intertidal and shallow subtidal habitats, and to Renewable Products indicators.

Research And Development Needs

The research and development needs described here are of a generic nature. The effort required to address the needs described below will vary for each chosen key indicator. It may range from a small university-based project to analyse historical data — to develop a national baseline for an indicator — to a major new national field survey of an indicator to establish a new baseline of natural dynamics that can be used as the benchmark for SoE reporting. There may also be unpredicted research issues; these will probably only become apparent as pilot trials and then full-scale national trials of the indicators are conducted. Some of the research issues may be combined in an operational sense, and so may aggregate into single tasks that could be contracted to a suitable research institution. For example, as remote sensing is a generic tool, the various remote sensing needs using, say, aircraft video might be combined into a single research task with outcomes relevant to a number of related indicators.

In this list of research and development needs, we identify major gaps in our knowledge at a range of levels — including distributional information on species and assemblages, technical issues such as a lack of widely available statistical tools appropriate to SoE purposes, a lack of sufficient experienced taxonomists, and a lack of synthesised data and information derived from existing biological data.

The needs for research are listed in priority order, although all are crucial to the success of the SoE reporting process.

1. Statistical tools

Robust statistical models and tools need to be developed to provide generic support for the SoE reporting process. There is a well-accepted need for inferential approaches and dealing with uncertainty in an explicit manner when reporting on the condition of ecosystems (National Academy of Sciences 1995). Without a scientifically based set of tools to aggregate, analyse and report on the quantitative data to be generated for each indicator, national SoE data may fail to be accepted and hence broadly used by science and management agencies. Also, the statistical characteristics of indicator data are a key part of assessing the value, for SoE purposes, of a monitoring design, and can be used to optimise monitoring designs. These tools will be crucial in the development of SOPs for each indicator.

Although there are many existing tools and statistical approaches available, none has been critically assessed for its direct relevance to national SoE needs. Also, to fulfil the goal of having the SoE indicators broadly accepted and used in various levels of government and the private sector, detailed and explicit guidance and instructions on the use of appropriate statistics will be needed. The objectives of an appropriate research project are to:

- review available statistical tools and approaches;
- conduct trials of selected tools and approaches in the context of representative case studies; and
- develop a recommended set of standard approaches to detecting change, statistical tools, and analysis methodologies appropriate to the anticipated range of national SoE national datasets.

2. Remote sensing trials

The research would trial national implementation of remote sensing for a selected suite of indicators in a range of representative case studies.

3. Offshore ecosystems

Offshore areas and the deep seas are a very major gap in terms of both an inventory of flora and fauna and our knowledge of ecosystem processes. The development of an inventory of deep-water species, assemblages and ecological processes (benthic and pelagic) and their distributions, and the biological diversity of offshore islands, in the EEZ is of the highest priority. The offshore and deep-water regions of the EEZ are a major Commonwealth responsibility. They are being subjected to increasing pressures for mining and fishing, and are subject to gradual changes related to climate variability. These areas are also of increasing international biodiversity interest because of their apparently highly localised (endemic) fauna. Important potential indicator groups that should be given detailed consideration in these offshore areas — and generally throughout the EEZ — include phytoplankton and zooplankton, benthic invertebrates, and species of sharks and rays.

Because of the cost and resource implications, there is probably a need for a whole-of-government approach to the exploration and development of the EEZ, and particularly for a highly coordinated and focused program of activities to develop an inventory of the living resources, including an evaluation of biodiversity values. Also included should be a costed program to provide detailed and comprehensive taxonomic support for the development of the inventory. The high cost of capturing information about the EEZ also means that this program should develop cost-effective procedures for prospective indicators based on innovative approaches to data collection — such as remotely sensed or automated systems, and/or opportunistic measurements in collaboration with other sectors of activity (e.g. shipping, mining and fishing). There may also be useful opportunities to link with important international programs that are represented by small projects in Australia — for example, the various aspects of the Global Ocean Observing System — and perhaps other international programs.

The major objectives for an EEZ exploration program would be to sample the living resources of the EEZ to establish the distribution and values of offshore and deepwater biodiversity, and to develop and evaluate prospective indicators. This information would then be used to plan an appropriate SoE reporting program, and to identify diverse and high-biodiversity-value areas of the EEZ where conflicts with wealth generation might be likely to arise.

4. National Standard Operating Procedures

This project would involve, for each Key Indicator, the design, development and trialing of the National SoE Standard Operating Procedures to permit (and encourage) comparable data collection in the various jurisdictions. Each SOP would be developed in relation to three important levels of effort and expertise:

- procedures for intensive and expert data capture and analysis;
- procedures for routine but intensive data capture and analysis; and
- procedures for volunteers and community groups (where appropriate).

A typical National SOP would address the following matters:

1. Objectives
2. Why is This Important?
3. Approaches
4. Sampling Design (local to national)
5. Equipment and Resources Required
6. Sample Collection Locations
7. Sampling Procedures and Logistics
8. Taxonomic Guidance
9. Equipment Maintenance
10. Safe Operating Procedures and Safety at Sea
11. Data Formats, Recording and Data Management
12. Data Analysis and Reporting
13. Quality Assurances: Design and Reporting
14. Real-Time Reporting and Distribution of Data.

There are a number of important existing initiatives in the development of standards for conducting routine data capture and interpretation in marine ecosystems. These include aspects of tropical marine resources (English *et al*. 1997), the ANZECC Water Quality Guidelines (in revision), and standard techniques for oceanographic data.

5. Development of baselines

Detailed assessment is needed of existing data for each indicator. Then as appropriate, after a National SOP is agreed, a national baseline of data (space and time) needs to be developed for each indicator, particularly characterising the natural variability in space and time at undisturbed locations.

6. National Reference Sites

The need here is to design and develop a network of SoE National Reference Sites to cover the major national ecosystem types. These range from saltmarshes and estuaries through lagoons, bays and coastal waters to the boundaries of the EEZ. This work would need to encompass sampling designs, costs for implementation, and phased levels of implementation to accommodate incremental development and implementation to match available resources. Also included should be a costed program to provide detailed and comprehensive taxonomic support for development of an inventory of taxa at the reference sites.

7. Community monitoring

Work is needed on the development of designs for, and trial implementation of, community monitoring and participation using selected key indicators, including intercalibration with more intensive science-based data-capture processes.

8. Case studies

Implementation of selected key indicators needs to be trialed at a range of scales — from local to national — in case studies in preparation for data gathering for the next SoE report.

9. Ecosystem integrity ("health")

Development and trialing are required of a consistent national framework for determining ecosystem integrity based on SoE indicators and SOPs. The key outcomes would be the development and implementation of a process for identifying surrogates for important ecosystem-level processes and structural aspects.

10. Development of multiple use models of the EEZ

Spatially based multiple use models of the EEZ need to be developed, based on the spatial boundaries of IMCRA subregions and the Marine Regions. This work will encourage the adoption of these spatial boundaries in various sectoral management frameworks, and greatly enhance the utility and value of the SoE indicators that are to be based on this same framework.

11. Sewage and stormwater detection

A more robust and rapid detection approach needs to be developed for the measurement of human pathogens contained in sewage and stormwater runoff.

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APPENDIX 1

Indicators considered for the key set but not included

This appendix lists (in Table 2) the proto-indicators considered for inclusion in the key set but ultimately excluded. They were excluded on one or more of the following grounds as indicated in the table.

1. Not of national importance

Proto-indicators were rejected if they:

- have only local relevance (even if they have a major impact locally);
- do not affect aspects of the environment that are widely spread or of major national importance; or
- are not elements of the environment of national importance (although they may have great local importance).

2. Overlap/duplication with other key indicators

Proto-indicators were rejected if they either duplicated or overlapped in terms of information content other indicators that met more of the selection criteria, or were deemed to meet them more efficiently.

3. Technical difficulties with measurement or interpretation

Proto-indicators were rejected if they had major perceived technical difficulties that seemed unlikely to be resolvable in the foreseeable future. These technical difficulties included:

- no currently operational (or nearly operational) technology for implementation of routine measurement protocols at the required scales of space and/or time;
- grossly excessive costs for routine implementation;
- no clear model existing or conceivable to interpret the data into a form to produce information useful for policy and management decisions.

Table 2

Proto-indicators not included in the key set

Short Title	Long Title	C/P/R	excluded because		
			1	2	3
aquaculture inputs	the use of imported feed, overseas parent stocks, or other materials in aquaculture operations	P		X	
beach litter	the extent of litter on beaches and coastlines	P		X	
beach pathogens	the occurrence and nature of human pathogens on swimming beaches	P			X
beach shoreline	the location of shorelines and the most seaward vegetation on the backshore of beaches	C		X	
beach type	classification of beach types, reassessed on an 8-year cycle	C		X	
beach usage	the number of visitors using beaches on estuaries and coasts	P		X	
certification programs	the number and coverage of programs designed to certify environmental performance at any level, and operational in Australia	R			X
community attitude surveys	targeted assessment of community attitudes towards marine and estuarine pollution, over-exploitation of resources, coastal degradation issues, and loss of biodiversity.	R		X	

contaminant loads	the loads of contaminants that are released to coastal systems	P			X
digital marine charts	the area of Australia's EEZ covered by digital charts for mariners	R	X		
dune classification	a bio-geo-physical classification of sand dunes based on height and shape	C			X
estuary classification	a bio-geo-physical classification of estuaries	C	X		
estuary health	the ecological "health" of estuaries	C			X
fishing bycatch	catch rates and species composition of fishery bycatch (non-target species)	C			X
gulfs and bays classification	a bio-geo-physical classification of the gulfs and bays	C	X		
gulfs and bays health	the ecological "health" of gulfs and bays	C			X
human pathogens	the incidence of water-borne disease in humans	P			X
hydrological regimes	the quantity and timing of freshwater discharges to estuaries and bays	P		X	
introduced species	the number and identity of introduced species in each IMCRA region and bioregion	P			X
islands and cays classification	a bio-geo-physical classification; the type and physical attributes of Australia's offshore islands and cays	C	X		
marine mammal contamination	contamination of mammals by pesticides and related chemicals	P			X
pest effects	nature and extent of detrimental effects of introduced species on native flora and fauna	C			X
recreational catch	the recreational catch of fish and other species, by estuary, subregion and region	C			X
recreational fishing	the number of recreational fishers, and an estimate of recreational fishing effort by gear type in each estuary, subregion and region.	P			X
responding to species outbreaks	responses to evidence of species outbreaks that threaten the environment or valuable resources	P			X
responses to pests	responses to evidence of introductions that threaten the environment or other valued resources	R			X
river discharges	the volumes and timing of discharges of rivers into estuaries	C		X	
sediment functions	the flux of dissolved oxygen into the sediments from overlying waters, and the concomitant release of ammonia, filterable reactive phosphorus and other chemical species	C			X
sensitive areas for shipping	the areas classified as Sensitive Areas for shipping purposes, and promulgated under the IMO auspices	R			X
ship ballast water	ballast water carried by ships and discharged into the EEZ (including ports and coastal waters)	P			X
turtle nesting	reproductive success of turtles	C		X	
zooplankton	long-term changes in species composition and abundances of marine and estuarine zooplankton species	C			X

*1 Not of national importance
2 Overlap/duplication with other key indicators
3 Technical difficulties with measurement or interpretation