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Coastal and Marine Resource Condition Monitoring – Scoping Project

Final NRM Report – Project 073007

Part 3 – Strategic framework for marine and coastal resource condition monitoring in the Pilbara and Kimberley regions of Western Australia.

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Cover image: Near pristine habitat at Roebuck Bay, Broome. Photo: Brett Human

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Abbreviations

AIMS – Australian Institute of Marine Science

CALM – Department of Conservation and Land Management, Western Australian Government (currently DEC)

CSIRO – Commonwealth Scientific and Industry Research Organisation

DEC – Department of Environment and Conservation, Western Australian Government

DEWHA – Department for the Environment, Water, Heritage and the Arts, Australian Government

DRS – Data Reporting System; implemented for the SoE reports

DoE – Department of Environment, Government of Western Australia (currently DEC)

DoF – Department of Fisheries, Western Australian Government

DoW – Department of Water, Western Australian Government

EPBC Act – Environment Protection and Biodiversity Conservation Act 1999

IMOS – Integrated Marine Observing System

LNG – liquid natural gas

MU – Murdoch University

NDT – northern development taskforce

NRM – natural resource management (funding body)

NWMRI – North West Marine Research Inventory

NWSJEMS – North West Joint Environmental Management Study

RCI – resource condition indicator

RCM – resource condition monitoring

SoE – State of the Environment reports

UWA – University of Western Australia

WA – Western Australia

WAM – Western Australia Museum

WAMSI – Western Australian Marine Science Institute

WC Act – wildlife conservation act 1950

Executive summary

The marine and coastal environment of the Pilbara and Kimberley region in north-western Western Australia contains many assets, including remote and near pristine habitats, unique habitats within Australia, unique fauna and flora; as well as assets of value to commercial and industrial ventures; and for recreational human usage. However, there is a lack of monitoring in the Pilbara and Kimberley marine and coastal environments. This is in large part due to the remoteness of the area, making access difficult, and consequently making monitoring programs expensive to run in the region.

In this report, resource condition, resource condition monitoring (RCM), and resource condition indicators (RCI) are defined and discussed in the context of implementing and operating a monitoring program. Issues of temporal and spatial scale are discussed, as well as the importance of having comprehensive baseline data. All biological parameters of a monitoring program are fundamentally dependant on baseline data. Attempting to initiate a monitoring program without baseline data will no doubt lead to the failure of that program. Measures used to assess the 'health' of a system, or RCI's, need to be repeatable and scientifically robust. Potential stressors to a system need to be identified and understood.

There is considerable debate and discussion about the use of RCI's in marine environments. Evidence is mounting that simplistic measures employed in earlier monitoring programs are ineffective, and ultimately not cost effective. Similarly, the use of physico-chemical measures and simplistic biological measures alone are outdated. The marine environment is complex therefore, in order to reflect that complexity, indicators themselves require complex data collection and complex analyses. The use of bioindicators is gaining popularity and scientific recognition. A suite of bioindicators, supported by a suite of physico-chemical RCI's is the only means for detecting change in a complex system and understanding why that change is occurring.

The fundamental and pre-planning elements of a monitoring program are presented. A monitoring program begins with clearly defining goals and objectives. From these, all other matters of monitoring stem. Detailed planning is essential prior to initialising the monitoring program because having to make changes once the monitoring has begun often results in the effectiveness of the monitoring program being compromised.

The management loop provided by Mount (2008) is adopted here. Repeated passes through a series of managerial and planning processes provides biological information on which to base the monitoring program, facilitates the setting of monitoring priorities, reports on whether managerial action needs to occur, and if the monitoring program is achieving its goals and objectives.

A set of criteria for RCI selection is provided, in light of what is needed from a RCI in complex systems. This process is fundamentally dependant on informative baseline data. Specifically excluded from RCI selection criteria are: ease of data collection; ease of data analysis; and low financial cost. While these are ideal properties of indicators, using them as criteria will almost certainly contradict the aims and objectives of monitoring in complex systems, ultimately resulting in the failure of the monitoring program.

Once the suite of indicators have been selected, baseline data is used to set trigger values for them, which are measured values that indicate that a change has occurred in the system that warrants further investigation. Trigger values need to be set using the precautionary principle, and if they prove to be too conservative, can be reset over time, with supporting evidence from ongoing monitoring data.

A reporting system is adopted from Scheltinga & Moss (2007), which employs a colour coded score card for quickly and effectively communicating to managers what actions, if any, need to be taken. Actions are prioritised using a cumulative scoring system, so that actions requiring the most urgent action obtain the highest scores, and are colour coded appropriately.

A process for motivating for monitoring funding is provided here. The process involves first calculating the estimated monetary worth of the environment that will be monitored. It is likely that this process will result in a multi-million dollar estimate. Then propose a percentage of this value that is needed for monitoring the intended system. Such arguments should provide greater leverage in gaining funds.

The final section is based on Scheltinga & Moss (2007). A list of stressors, including potential causes and signs of changes to that stressor, a list of potential indicators for the stressor, and a strategic management/ monitoring model is provided for each stressor. This is followed by a detailed explanation of each potential indicator, adapted from Scheltinga & Moss (2007).

Key Findings

- The marine and coastal environments of the Pilbara and Kimberley region of the northwest of Western Australia possess valuable assets across a broad range of value categories, yet monitoring programs and baseline data are limited.
- A unified monitoring program for the Pilbara and Kimberley marine and coastal environments is needed.
- A monitoring program cannot hope to achieve its outcomes and objectives in the absence of baseline data.
- Detailed planning is required of a monitoring program before its implementation. Baseline data will inform planning so that minimal changes are needed once the program is implemented.
- The use of simplistic resource condition indicators has proven ineffective in complex environments, such as marine and coastal environments. The continued use of simplistic indicators will compromise the effectiveness of a monitoring program.
- It is no longer acceptable to use: ease of data collection, ease of data analysis, and low financial cost; as criteria for selecting resource condition indicators. Such criteria contradict the aims and objectives of monitoring in complex systems.
- Management loops have been adopted from Mount (2008), and a reporting system has been adopted from Scheltinga & Moss (2007), to promote consistency and compatibility with monitoring programs elsewhere in Australia.
- Funding for monitoring programs should be motivated through requests for percentages of the estimated monetary worth of the system to be monitored.

Project aims and background

A large coastal and marine resource condition monitoring (RCM) project was developed for the Pilbara and Kimberley regions. Unfortunately this larger project did not eventuate. However, to continue with developing our understanding of RCM in this region a smaller scoping study was developed

This scoping study has three primary aims:

1. Knowledge review and gap analysis - undertake a desktop study of the current coastal and marine resource condition monitoring.
2. Undertake a short field program to inform the development of monitoring protocols in two intertidal environments.
3. Develop a Strategic Framework with recommendations and a suggested approach to inform and guide a future Coastal and Marine RCM Program for the Pilbara and Kimberley Regions.

This document addresses the third aim of the project, providing a strategic framework from which to conduct future resource condition monitoring for the marine and coastal environments of the Pilbara and Kimberley region.

The report "Knowledge review and gap analysis: Resource condition monitoring in the Pilbara and Kimberley regions of Western Australia" (Human & McDonald, 2009) addressed the first aim of the project by providing a current state of knowledge through a comprehensive review of the research and monitoring literature known for the marine and coastal environments of the Pilbara and Kimberley region. From that literature review, a knowledge gap analysis identified key areas that required further research. These knowledge gaps were then presented to stakeholders, through a series of stakeholder workshops conducted in the region, to prioritise those knowledge gaps for future research. The findings from that report were incorporated into this strategic framework during its development.

The second aim of this project resulted in a report, "Field trial of potential resource condition indicators, and an exploration of the utility of remote sensing, for mangroves and intertidal mud flats in the Pilbara - Pilot study" (Human *et al.*, 2010). That pilot study compared numerous remote sensing, and ground truthing techniques for potential use in mangrove and mud flat monitoring. Numerous potential resource condition indicators for those habitats were also critically assessed. The methodology critique performed in that report has informed the development of the current strategic framework.

This document

This document addresses the third component of the scoping study and provides a strategic framework for future marine resource condition monitoring in the Pilbara and Kimberley regions. Some of the key findings from Human & McDonald (2009) included: that the relative amount of research and monitoring effort that has been invested in the marine and coastal environments of the Pilbara and Kimberley region is low compared to elsewhere in Australia; that there is a paucity of baseline data for resource condition monitoring of the marine and coastal environments of the Pilbara and Kimberley; and that there is a need, and general agreement across stakeholder groups, including government agencies and the general public, that long term resource condition monitoring of the marine and coastal environments of the Pilbara and Kimberley is a high priority.

The aim of this document is to provide a strategic framework from which to design and undertake resource condition monitoring of the marine and coastal environments of the Pilbara and Kimberley region. The report is divided into two sections:

Section A of this document details the considerations that need to be taken into account when formulating a resource condition monitoring program. Firstly, the aims and objectives of the monitoring program need to be identified. Once this has been established, this document provides the framework for developing the monitoring program based on those aims and objectives. The use and relevance of resource condition indicators (RCI's) are discussed. The use of simplistic RCI's are not effective in complex environments, and a suite of indicators are required that reflect the ecological processes and functions for a particular environment. Also provided is a novel tactic for motivating for monitoring funding based on the estimated value of the environment to be monitored.

Section B of this document provides a list of the stressors that are encountered in the marine and coastal environments of the Pilbara and Kimberley region. Accompanying each stressor is a comprehensive list of potential causes and signs of changes to that stressor, potential resource condition indicators that can be used to monitor the stressor, and a strategic management/ monitoring model (current managing agency, primary monitoring body, other research bodies). Detailed explanations of the resource condition indicators (RCI) used for all of the stressors are then provided. Here, the RCI is defined, a rationale provided for the use of the RCI, key information on data gathering and analyses for the RCI, issues linked to the RCI, monitoring locations and frequency, data measurement methods, data analysis and interpretation, data storage, further references for the RCI, and a glossary. A total of eight stressors and thirty-one RCI's are detailed in this section.

SECTION A – A Strategic Framework

1.0 Introduction

Habitat loss and its effects on biodiversity are a growing global concern. Loss of habitat is a major cause of the decline of coastal species (DEH, 2008b). Changes in distribution, such as range extensions or reductions, are also of interest, especially during times of climate change, as they may be indicators of significant ecological changes underway. Some of the existing, imminent, and proposed threats to marine habitat integrity in these areas are in close proximity or adjacent to existing and proposed marine conservation reserves, created to conserve important ecological and social values. If pressures or threats are left unchecked, serious damage or irreversible loss is likely to occur. However, we currently know little about the characteristics of key habitats or how they might respond to any stressors. State-wide, there is a significant lack of monitoring at unimpacted reference sites and a great need for this type of monitoring to gauge natural variability, inform target setting, and differentiate between the effects of human and natural influences. The need for this critical baseline information is growing daily (Human & McDonald, 2009).

The Western Australian coastal and marine environment is a vast area with 20,800km of coastline, including islands (Trewin, 2006), and spans both tropical and temperate climates. With the exception of Ningaloo Marine Park, we know almost nothing of the condition of the marine resources of the arid-tropical Pilbara and Kimberley regions, yet the high marine biodiversity and recreational values of these areas are recognised at a national and international level (Human & McDonald, 2009).

1.1 The Pilbara and Kimberley region

The Pilbara is of great strategic and economic importance for the State and Commonwealth. The area supports a wealth of offshore oil and gas resources For example, the recently approved Gorgon project will target a gas reserve of 40 trillion cubic feet, and is expected to boost Australia's gross domestic product (GDP) by AU$64.3 billion (http://www.gorgon.com.au). The Pilbara has the country's largest export ports, some of which are currently expanding or have proposals to expand. There are also a number of new large-scale LNG and industrial activities proposed throughout the region, most of which will rely on large marine infrastructure to facilitate export. The region also has great tourism potential. It is also an area that supports some of the country's most unique and highly biodiverse marine habitats (e.g. nearshore coral reefs develop due to the limited run-off from the land, and arid-zone tropical mangrove communities are also present) (CALM, 2005; DoE, 2006; NWSJEMS, 2007; DEWHA, 2008; and Wood & Mills, 2008).

The Kimberley is one of the most remote and uninhabited stretches of the Australian coastline. Apart from a few indigenous communities, the only coastal settlements are the small ports of Derby and Wyndham. Despite this remoteness, the remarkable natural beauty of the coastal environment means that commercial tourism operations are already well established, and major development applications by oil and gas industries are currently being planned. Assessment of the potential impact of all of these activities is hampered by the paucity of baseline environmental data for any of the marine communities in the Kimberley. What little is known of these habitats indicates that they tend to be locally very complex and diverse, and frequently not found elsewhere in Western Australia (NWSJEMS, 2007; DEC, 2008; DEWHA, 2008; Fry *et al.*, 2008; NDT, 2008a,b; and Wood & Mills, 2008).

1.2 Key features within the Pilbara and Kimberley

From a commonwealth perspective, fourteen key ecological features for the north-west marine bioregion were identified by DEWHA (2008). The key ecological features identified, that are relevant to this study include: the commonwealth waters surrounding Ashmore Reef and Cartier Island; the commonwealth waters surrounding Scott and Seringapatam reefs; demersal slope fish communities; the commonwealth waters adjacent to Quaondong Point; the Glomar Shoals; commonwealth waters surrounding the Rowley Shoals; and Exmouth Plateau. In that same report, 24 areas were identified as important areas for threatened and migratory species listed in the EPBC Act.

Downs *et al.* (2005), using dramatic examples of coral reef monitoring failures at a global scale, highlighted the need for informed monitoring, i.e. monitoring programs that have tangible objectives, goals, and reporting components. A further fundamental component, which is often overlooked, is a management model that is capable of implementing action(s), when results from monitoring dictate that they are needed, in a timely and effective manor. Without this final component, one could argue that a monitoring program is pointless if the capability to implement necessary interventions does not exist. Legislation is needed at state and federal levels to ensure that such managerial components are in place and are effective.

1.3 Major habitats found in the Pilbara and Kimberley

1.3.1 Coral reefs

Several types of coral reefs characterise the coral communities of the Pilbara, which comprise both turbidity-adapted communities of inshore environments and offshore clear-water coral communities. In the West Pilbara, offshore coral banks and platform reefs are predominant, whereas around the Dampier Archipelago, the Montebellos, the Muirons, and other offshore islands, extensive fringing reefs predominate (DoE, 2006). Corals are protected throughout Western Australia under the WC act, although commercial coral collection is managed through the FRM act (CALM, 2005). Immediate threats identified by CALM (2005) to corals include fishing, and physical degradation brought about through trampling and coral collecting, with other potential threats including eutrophication, exotic pest introduction, and elevation of water temperatures (Human & McDonald, 2009).

Human & McDonald (2009) noted that fringing coral reefs in the Kimberley are more extensive than that of Ningaloo, and these fringing coral reefs, along with extensive seagrass meadows, have only been partially mapped. All of these habitats contribute to the productive Kimberley coastal waters (DEWHA, 2008). The ecological interaction of within and between these communities are virtually unknown (Wood & Mills, 2008).

1.3.2 Mangroves

Human & McDonald (2009) noted that mangroves in the Pilbara and Kimberley form small but sometimes complex communities in embayments and on the sheltered shores of many offshore islands. It is rare for mangrove communities to occur in arid conditions, therefore the mangroves of the Pilbara and Kimberley are of great scientific importance. Mangrove communities are protected throughout Western Australia under the Wildlife Conservation Act 1950 (WC Act) and any proposed development near mangroves are subject to an environmental impact assessment (CALM, 2005). Semeniuk (1993) characterised mangroves of the Pilbara and Kimberley as conspicuous and extensive in association with muddy substrates, forming wide forests in some parts of the mainland shore.

The whole mangrove system of the region is considered important in order to maintain nutrient cycles and productivity of the coastal zone. These coastal forests are important for many reasons. Aside from providing a unique habitat for a variety of different creatures, the mangroves also help protect the shoreline and act as carbon sinks (Final Guidance No. 1, Guidance Statement for Protection of Tropical Arid Zone Mangroves Along the Pilbara Coastline. April 2001; and Human & McDonald, 2009).

Human & McDonald (2009) also noted that there has been extensive loss of mangrove communities in the Pilbara and Kimberley regions due to industrial activities, however those mangrove communities that still exist are in near pristine condition. Physical disturbance from industrial development, trampling from recreational fishers, and four-wheel drive vehicles, have been identified as immediate threats to these mangrove communities. Pollution from various sources is a further potential threat. Management through monitoring and education has been proposed (CALM, 2005).

1.3.3 Intertidal sand and mud flats

Fringing mangroves of the region are typically backed by extensive intertidal flats that are characterised by a rich and diverse fauna of burrowing invertebrates, and the functioning of the mangrove ecosystems are strongly linked to these intertidal flats. The intertidal flats are also major habitats for migratory birds that use the mud flats as feeding grounds. In particular, the Kimberley has extensive tidal sand and mud flats, which are key habitats for complex invertebrate communities (DEWHA, 2008; and Human & McDonald, 2009).

1.3.4 Seagrass beds

Algal and seagrass beds occur in the Pilbara and Kimberley regions, however, are not as extensive as off the west and south coasts of Western Australia, and are primarily found in shallow habitats such as intertidal zones, lagoons, mangrove swamps, and around islands. Seagrass and algal beds are an important element of the region's ecosystems and they support a diverse fauna including herbivorous fishes, turtles and dugongs (DoE, 2006; and Human & McDonald, 2009).

Human & McDonald (2009) noted that seagrasses are protected throughout Western Australia under the Wildlife Conservation Act 1950 (WC Act) and managed through the Fish Resources Management Act 1994 (FRM Act). Any proposed developments near seagrasses are subject to an environmental impact assessment (CALM, 2005).

2.0 Defining resource condition, monitoring, and indicators

2.1 Resource condition

Resource condition is defined here as the current status of a particular habitat or environment, in reference to the "health" of that system, and the ability of that system to tolerate impacts without significantly altering the system. This is further elaborated by Borja *et al.* (2008), "… the concept of environmental status [= resource condition] takes into account the structure, function and processes of marine ecosystems bringing together natural physical, chemical, physiographic, geographic and climatic factors, and integrates these conditions with the anthropogenic impacts and activities in the area concerned".

From a management perspective, it would be ideal to know the resource condition of a particular habitat or environment when in pristine condition. This eliminates anthropogenic influences on that system, reducing influences to that system to those that are natural. However, such knowledge is usually absent, and it is rare to find systems that are free from human impact. The lack of baseline environmental data for tropical systems compared to temperate systems, has been recognised elsewhere (Fichez *et al.*, 2005; and Human & McDonald, 2009).

However, given the remoteness of some of the Pilbara and Kimberley marine and coastal environments, some of the habitats there are regarded as near pristine (Wood & Mills, 2008). However, a pristine, or near pristine environment does not necessarily mean that such an environment is without stresses. Gilmour *et al.* (2006) suggest that due to the extreme conditions in the Pilbara, some corals and communities exist at close to their physical limits, particularly inshore reefs. The extreme tidal ranges experienced in the Kimberley, also subject various habitats to inundation and exposure cycles, potentially leading to high stress levels in those systems (see *3.4 Indicators and complex systems* for further discussion on the ramifications of monitoring naturally stressed environments).

2.2 Resource condition monitoring (RCM)

It is recognised that the marine environment is heavily influenced, in some instances, by multiple anthropogenic impacts, which result in physical and chemical changes, that ultimately change the biological processes in marine environments, often resulting in environmental degradation (Borja *et al.*, 2008). It is because of such scenarios that monitoring of resource condition is essential in areas where anthropogenic impacts are likely to significantly change an environment. Just as important, is monitoring marine protected areas and reserves, so that anthropogenic impacts can be separated from natural processes (Alcaraz-Segura *et al.*, 2009).

Human & McDonald (2009) defined monitoring as, "a structured sampling regime with repeated surveys, at consistent intervals appropriate to the nature of the study, of established survey sites using a uniform sampling methodology over a long term time period". This definition incorporates necessary elements of a monitoring program that are required to ensure that the monitoring program is effective. These elements include - temporal scale, spatial scale, baseline data, and repeatable, robust methodologies of data collection and analyses. To extend this definition of monitoring to resource condition monitoring, then elements of management need to be incorporated (see *3.2 Fundamentals and pre-planning*).

2.2.1 Temporal scale

Several studies have highlighted the benefits of long term monitoring and the use of appropriate temporal scales in monitoring. Long term monitoring is needed in order to understand the temporal variability of a system, which is necessary in separating natural influences from anthropogenic influences. Adjeroud *et al.* (2005) demonstrated the ability of separating anthropogenic and natural influences using long term monitoring. Likewise, a 25 year monitoring program was able to rule out atmospheric oscillation cycles from their study because the length of the monitoring included periods of both extremely wet and dry weather conditions (Alcaraz-Segura *et al.*, 2009). This last point has particular relevance for the Pilbara and Kimberley given the strong seasonality of the region (tropical wet and dry seasons), and how these may change in the face of climate change.

Just as important as sustained monitoring, is the temporal scales at which habitats are monitored. Sampling intervals need to be appropriate for the habitat/ environment being monitored. This is dependant on the expected amounts of change that could occur within a given time period for a particular system. For example, in a highly dynamic habitat, change occurs quickly, therefore it would be necessary to monitor more frequently. Compare this with a habitat that is more static, where sampling does not need to occur as frequently. For instance, intertidal habitats are very dynamic therefore would require more frequent sampling compared to demersal assemblages of the lower continental slope, which tend to be more static.

2.2.2 Spatial scale

Adjeroud *et al.* (2005) also demonstrated that multi-spatial scale surveys successfully accounted for temporal variability. Understanding and comparing changes that are occurring on local, regional, and global scales allows better identification of which influences are impacting at varying degrees at the different spatial scales. For example, it might be found that localised impacts are negligible compared to the change being recorded at the regional scale (Adjeroud *et al.*, 2005). In contrast, Alcaraz-Segura *et al.* (2005) found significant differences in the rates of change between sites that were in close proximity to each other. These two scenarios require very different management actions, highlighting the need for a well planned management response that has considered management actions that may be needed for various spatial scales.

It was recognised by CSIRO (1998) that a range of scales in space and time apply to environmental management. Careful account must be taken of this when selecting indicators. The scale associated with the indicator will depend on the objective of management. National State of the Environment reporting will use many continental scale indicators, reflecting the national needs it serves, while local government and individual landholders will mostly use indicators at a much finer scale. The same indicator may be relevant at both local and regional scales; but, sometimes, different indicators will be needed for different scales.

The effects of spatial and temporal conditions, and the profound effects they can have on the ecological processes of a system, are best highlighted by the findings of Coelho *et al.* (2007). In reference to coastal lagoons, Coelho *et al.* (2007) found that when lagoons are isolated from the sea and are mainly influenced by rivers, they present characteristics similar to still waters; in contrast to when lagoons are connected to the sea, with tidal influence, when they function like small estuaries. This example highlights the complexity that can be found within marine and coastal environments, and the need to use appropriate spatial and temporal scales.

2.2.3 Baseline data

Baseline data is data that provides some background environmental information for the system to be monitored, and how that system behaves (CSIRO, 1998). What is there? How does it respond to various stresses? How much stress is needed to evoke a response? What are the natural (cyclical/ seasonal/ diurnal) variables? What happens if the system strays outside this natural range? How disturbed is the system from a pristine state? Will natural functions be slowly degraded, or is there a point at which the whole system will suddenly collapse? Can the system recover from disturbance/ collapse?

The answers to these questions inform the monitoring program parameters by providing a deeper understanding of the system. With such understanding, it is possible to identify threats and pressures more accurately; have an understanding of the resilience of the system, which in turn informs setting of trigger values (see *3.6 Trigger/ threshold values*); and also provides an understanding of the spatial and temporal scales involved with the system, which in turn informs the selection of appropriate indicators (see *3.5 Philosophy of indicator selection*).

It was proposed by CSIRO (1998) that a monitoring program is often needed for indicators to establish the facts and the trends, and that a trade-off may be necessary between the cost of monitoring and the quality of the information acquired. However, employing such an approach compromises the effectiveness of the monitoring program, while such facts and trends are established. The result may be that particular indicator(s) were inappropriate for the study, resulting in significant losses of time and financial costs. In the process, the system that was supposed to be monitored may have been significantly impacted.

The use of pilot studies or prior research was recognised by the Department of Environment and Heritage (DEH, 2008a) to assist in the selection of appropriate reference/ control sites, and underscored the importance of baseline studies. Furthermore, the choice of monitoring locations should correspond with the scale of the perceived impacts, which may in turn dictate the choice of suitable indicator taxa or assemblages (DEH, 2008a). Human *et al.* (2010) conducted a pilot study to assess various potential resource condition indicators and the use of remote sensing for monitoring mangrove habitats in northwestern Australia. This pilot study highlighted the need for baseline data, and showed that without appropriate baseline data, inferences made from uncalibrated remote sensing imagery would be positively misleading. The ability to make appropriate and correct management decisions, from a resource condition monitoring program that lacked baseline data, is remote.

CSIRO (1998) recognised that without system understanding, it can be difficult to select and interpret indicators, and to be sure that the indicators will provide useful, credible, and statistically valid information. The better an ecosystem is understood, the easier it is to select the best indicators and assess what changes in them mean. Normally, monitoring a complex natural system requires an integrated suite of indicators. The better our understanding of the system and the causal relationships within it, the smaller that suite can be. Understanding cause and effect relationships will also make it easier for managers to decide what action to take.

2.2.4 Repeatable and robust methodologies

A robust and effective monitoring program needs repeatable and robust methodologies of data collection and analyses. To be certain that changes detected by monitoring are actually occurring in nature and not simply a result of measurements taken by different people or in slightly different ways, detailed and exacting monitoring protocols must be developed and implemented as part of all long-term monitoring programs (Oakely *et al*., 2003). Robust and repeatable measures increase the precision of estimates, and since precise estimates are less variable, then smaller changes to a system can be detected (Godínez-Alvarez *et al.*, 2009), providing greater confidence in the overall performance of the monitoring program.

CSIRO (1998) recognised the need for consistency across jurisdictions and that the same indicators should be used in all States and Territories and, where appropriate, be consistent with those used overseas (see *2.4 Resource condition indicators*). However, CSIRO (1998) also recognised that environmental and management variations will often make consistency a challenging goal to achieve.

2.3 Stressors

Scheltinga & Moss (2007) define a stressor as a component of the environment that when changed has an impact on that environment. Stressors include things such as habitat, hydrodynamics, litter, pests, sediment quality, species composition, nutrients, toxicants, and water quality.

Scheltinga & Moss (2007) provided the example of nutrients as a stressor. Nutrients are naturally found in waterways, however, the actual amounts of nutrient entering a waterway, and hence the actual concentrations occurring in the waterway, can change as a result of human activities, e.g. water run-off from crops which have had fertiliser applied, can enter waterways and alter its nutrient concentrations. The increased nutrient load will likely effect multiple ecological processes within that waterway, as well as ecological processes in habitats directly or indirectly influenced by that waterway.

2.4 Resource condition indicators (RCI)

The ever growing number of RCI's, and debate about what an RCI is (or should be) and how to use them, continues *ad nauseam* (CSIRO, 1998; Ward *et al.*, 1998; Edinger *et al.*, 2000; Chou *et al.*, 2003; Jaureguizar *et al.*, 2003; Kabuta & Laane, 2003; Diaz *et al.*, 2004; Mirto & Danovaro, 2004; Scheltinga *et al.*, 2004; Adjeroud *et al.*, 2005; Desa *et al.*, 2005; Fichez *et al.*, 2005; Marín-Guirao *et al.*, 2005; Moss *et al.*, 2005; Reiss & Kröncke, 2005; Sagert *et al.*, 2005; Sleeman *et al.*, 2005; Anderson *et al.*, 2006; Eyre *et al.*, 2006; Gilliers *et al.*, 2006; Gilmour *et al.*, 2006; Mount, 2006; Natural Resource Management Ministerial Council, 2006; Salas *et al.* 2006a,b; Souter & Mackenzie, 2006; Willis *et al.*, 2006; Coates *et al.*, 2007; Coelho *et al.*, 2007; de Voogd *et al.*, 2007; Elliott & Quintino, 2007; Giri *et al.*, 2007; Pinedo *et al.*, 2007; Romero *et al.*, 2007; Sasal *et al.*, 2007; Scheltinga & Moss, 2007; Wu & Wang, 2007; Zettler *et al.*, 2007; Borja *et al.*, 2008; Casé *et al.*, 2008; DEH 2008a,b; Fisher *et al.*, 2008; Fukumori *et al.*, 2008; Hale & Heltshe, 2008; Henriques *et al.*, 2008; Johnston *et al.*, 2008; Juanes *et al.*, 2008; Martinho *et al.*, 2008; Mount, 2008; Pérez *et al.*, 2008; Puente *et al.*, 2008; Schultz, 2008; Uthicke & Nobes, 2008; Yemane *et al.*, 2008; Alcaraz-Segura *et al.*, 2009; Beyene *et al.*, 2009; Bozcaarmutlu *et al.*, 2009; Chang *et al.*, 2009; Courrat *et al.*, 2009; Dauvin & Ruellet, 2009; Dye, 2009; Einoder, 2009; Fancy *et al.*, 2009; Fry *et al.*, 2009; Godínez-Alvarez *et al.*, 2009; Goodsell *et al.*, 2009; Herrera-Silveira & Morales-Ojeda, 2009; Lucrezi *et al.*, 2009; Montefalcone, 2009; Ojeda-Martínez *et al.*, 2009; Viehman *et al.*, 2009; and Human *et al.*, 2010). This lengthy debate is somewhat justified however, given that there is more evidence coming to light suggesting that the use of a limited number of indicators, and/or the use of overly simplistic indicators are ineffectual, often compromising monitoring programs. The newer findings contradict the conventional wisdom of funding bodies, which require few and simple indicators to be used in order to keep monetary costs to a minimum.

CSIRO (1998) defined an indicator as a significant physical, chemical, biological, social, or economic variable, which can be measured in a defined way for management purposes. However, it is becoming apparent that selecting appropriate indicators that truly reflect physical, chemical, and biological change in an environment is a complicated process. Adjeroud *et al.* (2005) recommended that monitoring programs would benefit from having multiple, complimentary indicators. In the case of coral reefs for instance, one would chose an indicator for measuring diversity changes, an indicator for abundance and cover change, and an indicator for recovery potential (Adjeroud *et al.*, 2005). Anderson *et al.* (2006) stated that the most significant applications of resource condition indicators should be to assess ecological condition, diagnosis of specific stressors, and forecasting of potential changes in populations.

CSIRO (1998) recognised that good indicators encapsulate knowledge, providing an essential tool for understanding and for management purposes, at multiple scales. They are of great potential benefit as guides for action and to help measure its success, but must be designed with clear objectives and interpreted carefully. CSIRO (1998) also recognised that indicators are not an end in themselves. Indicators help define the nature and size of environmental problems, set goals for their solution, and track progress towards those goals.

A further limiting factor in the choice of indicators is that a full understanding of the implication of a change in an indicator is often lacking. Although studies are underway, understanding the relationship between the response of an indicator and the variable it is supposed to indicate, are not well understood in most instances. Even where indicators have been tested in laboratory studies, inference cannot reliably be extrapolated beyond the data because such studies have been conducted at unrealistically short temporal scales (Goodsell *et al.*, 2009). Low confidence in indicators highlights the need for baseline data to determine if indicators are truly appropriate and useful (see 2.2.3 Baseline data).

Other grounds for the need of baseline data in determining useful indicators is that an observed response of an indicator may be due to variation in other environmental conditions rather than the putative environmental stress (Goodsell *et al.*, 2009). Such discrepancies will also be solved when long term data are collected and natural variations in a system are better understood (see *2.2.1 Temporal scale*).

Temporal and spatial variability may also compromise statistical analyses of proposed indicators. For example, Reiss & Kröncke (2005) found that univariate indices such as the Shannon–Wiener index or the Hurlbert Index for the assessment of the ecological status of marine benthic environments are not appropriate if the seasonal variability is high. Furthermore, Reiss & Kröncke (2005) found that seasonal variability differs between marine regions under different environmental conditions. Thus, the choice of the adequate index, which is essential for the assessment of the ecological quality of marine regions, might depend on the research or monitoring topic, as well as on the study area. Having baseline data for a system will inform the temporal and spatial scales necessary for a particular monitoring program, and which indicators are appropriate at those scales, thereby reducing the occurrence of fundamental errors such as the use of inappropriate statistical analyses.

2.4.1 Physical and chemical indicators

Physical and chemical indicators do provide valuable information with regards to stressors such as pollutants, however, such measures are too simplistic to capture the impact that the various physico-chemical measures are having on a system. For example, organisms are often exposed to complex mixtures of pollutants, and chemical analyses do not reveal the impact of these pollutants on organisms (Chou *et al.*, 2003; and Bozcaarmutlu *et al.*, 2009). This is further complicated by the fact that concentrations of contaminants may be too low to be detected using chemical or physical measures, despite producing adverse biological effects, particularly when chronic processes such as bioaccumulation are considered (Goodsell *et al.*, 2009).

Physical and chemical indicators are often highly variable, particularly in coastal and inter-tidal environments (Courrat *et al.*, 2009; and Human *et al.*, 2010). For example, Courrat *et al.* (2009) found that although salinity was a fundamental property in estuaries, its variability required complicated modelling to account for any effects salinity had on populations. The paradox of collecting enough physico-chemical data to be able to decipher this variability is that data is often collected in such quantities that monitoring studies are frequently overburdened with irrelevant data (Fichez *et al.*, 2005).

Despite the shortcomings of physico-chemical measures to independently act as resource condition indicators, when used in combination with other types of indicators, these measures can provide useful insights into the source of environmental stresses (see *2.3.2 Biological indicators (Bioindicators)*), thus facilitating informed management action.

2.4.2 Biological indicators (Bioindicators)

The use of bioindicators, a species or species group that are considered to reflect the health of the habitat they occupy, has been extensively explored, and numerous taxonomic and functional groups have been examined for use as bioindicators including plankton, molluscs, fish communities, etc (Chou *et al.*, 2003; Anderson *et al.*, 2006; Coates *et al.*, 2007; Coelho *et al.*, 2007; Casé *et al.*, 2008; Johnston *et al.*, 2008; Bozcaarmutlu *et al.*, 2009; Courrat *et al.*, 2009; Goodsell *et al.*, 2009; and Lucrezi *et al.*, 2009).

The use of bioindicators is attractive because chemical and physical analyses do not reveal the impact of these factors (such as pollutants, for example) on organisms. The use of biochemical markers fulfills this purpose (Bozcaarmutlu *et al.*, 2009). Bioindicators are also used as a surrogate for a biological community because identifying all species in a community is time consuming, expensive, requires specialised expertise and is rarely undertaken in long term monitoring studies (Johnston *et al.*, 2008). Furthermore, the use of bioindicators takes into account their ecological function (Courrat *et al.*, 2009), and ecological function has been a key feature discussed in the development of bioindicators (Chou *et al.*, 2003; Anderson *et al.*, 2006; Coates *et al.*, 2007; Coelho *et al.*, 2007; Casé *et al.*, 2008; Johnston *et al.*, 2008; Bozcaarmutlu *et al.*, 2009; Courrat *et al.*, 2009; Goodsell *et al.*, 2009; and Lucrezi *et al.*, 2009).

Lucrezi *et al.* (2009) discussed the diverse concepts, applications, and definitions of bioindicators. These concepts include 'keystone' species (strong interactions with other species), 'umbrella' species (large habitat range), 'dispersal-limited' species (demonstrated site fidelity), 'resource-limited' and 'process-limited' species (sensitive to changes in a specific ecological resource or process), and 'flagship' or 'iconic' species (attract public support).

Desirable properties of a bioindicator is that the bioindicator is sensitive to changes within its habitat; the sensitivity is known for particular stressors; accumulates contaminants from the environment and accurately reflects environmental levels; are influenced by bottom-up (physico-chemical) and/or top-down (ecological) factors; or display some other measurable response to a stressed system, such as changes in behaviour or physiology; economic and social value of species is known; life-history (including life span and phases) understood; habitat-specificity known (habitat specialists maybe more sensitive to changes in habitat structure); and population dynamics known (stable species populations may be simpler to monitor). Also, the presence or absence of a bioindicator might confer the level of impact that has or hasn't occurred in a habitat, for example, some species occur only in pristine environments, whereas other species only occur in highly impacted environments (Chou *et al.*, 2003; Coelho *et al.*, 2007; Casé *et al.*, 2008; DEH, 2008a; and Goodsell *et al.*, 2009). Rare and highly variable species should be avoided as a means of monitoring coastal and marine environments (DEH, 2008a).

To further illustrate the concept of a bioindicator, plankton respond to low dissolved oxygen levels, high nutrient levels, toxic contaminants, poor food quality or abundance, and predation. By examining biomass, abundance, and species diversity, plankton communities provide insight for multiple ecological processes (Coelho *et al.*, 2007; and Casé *et al.*, 2008). Similarly, fish communities can be described according to a variety of characteristics such as composition, trophic structure and diversity of the assemblage, as well as abundance and biomass of the individuals, and trends in one or more of these community attributes can be used to monitor the ecological functioning of a particular ecosystem (Coates *et al.*, 2007).

Johnston *et al.* (2008) recognised that the identification of appropriate indicator species can be difficult and frequently requires some prior knowledge of the system to be monitored and some background information on the species that occur there. Before suitable indicator species can be identified, the particular attribute of the environment to be monitored needs to be defined as this will determine what species or suite of species are chosen as indicators. Again this highlights the need for baseline data of a system prior to monitoring (see *2.2.3 Baseline data*).

Bioindicators however, are not an all-encompassing solution for monitoring resource condition. Although bioindicators are the fundamental metrics needed to alert us to potential detrimental effects at any given site, without supplemental information, the potential causes of stress to the system cannot be identified. In turn, managers lack the information needed to take appropriate action (Adjeroud *et al.*, 2005; and Anderson *et al.*, 2006). It is in these circumstances that physico-chemical indicators may provide the answers needed for appropriate managerial action. Therefore, it is not appropriate to exclude physico-chemical indicators from a monitoring program in favour of using only bioindicators.

3.0 Monitoring framework

3.1 Legislation and guidelines for monitoring

The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) provides the overarching framework for management of Australia's national and international marine environmental responsibilities (Borja *et al.*, 2008). Borja *et al.* (2008) provide a detailed review of the monitoring legislation applicable to Australia. Briefly, the Natural Resource Management Ministerial Council endorsed the National Natural Resource Management Monitoring and Evaluation Framework (National M&E Framework) in 2002. The National Framework is based on a set of principles for the monitoring, evaluation and reporting on natural resource condition. The design of an assessment framework is largely dependent upon its objectives.

A summary of the international, commonwealth, and state legislation for the North West Shelf is provided by Gordon (2006). Most of these are applicable to the Pilbara and Kimberley regions within the scope of this report.

3.2 Fundamentals and pre-planning

Numerous reports and studies have provided elements that are necessary for monitoring programs (Oakley *et al.*, 2003; Diaz *et al.*, 2004; DEH, 2008a,b; Fancy *et al.*, 2009). These elements have been compiled into the following checklist for establishing a monitoring program:

1. Clearly define goals and objectives;
2. Compile and summarise existing information;
3. Delineate, or classify, regions of habitat that can be quantitatively defined (in time or in space) according to their physical, chemical, and biological character;
4. Identify clear relationships between anthropogenic disturbance and key ecological attributes of the target habitat and/or species, where possible;
5. Develop conceptual models;
6. Incorporate predictive models and other theoretical approaches;
7. Develop an overall sampling design;
8. Establish credible methodologies so that data meet defined standards of quality with a known level of confidence, and stand up to external review;
9. Ensure that methodologies detect changes over time and with changes in personnel;
10 Ensure that methodologies allow comparisons of data among places and agencies;
11. Develop monitoring protocols;
12. Assess and monitor the status of ecosystem performance relative to recent historical system states and suitable reference sites, including protected areas;
13. Gather contextual data pertinent to the resource condition indicator being considered;
14. Prioritise and select indicators;
15. Develop a set of resource condition indicators to measure progress toward the monitoring objectives on a long term basis;
16. Establish data management, analysis, and reporting procedures (management loops);
17. Establish action plans for various management scenarios, prioritising those considered high risk and/or likely.

The aims that should be integral to a resource condition monitoring program of marine environments were highlighted by Borja *et al.* (2008). The aims should include: multidisciplinarity, inherent in the teams involved in their implementation; integration of biotic and abiotic factors; accurate and validated methods for determining ecological integrity; accurate and validated methods for determining the extent and effect of human uses and impacts; adequate indicators to follow the evolution of the monitored ecosystems; use of protected areas as means of conserving and managing viable representative examples of marine environments, especially coastal areas, where greatest anthropogenic inputs occur; and the use of some early warning systems for abrupt changes in environmental conditions.

Oakley *et al.* (2003) motivates for the development of detailed monitoring programs prior to implementation. Their basic argument is that to make changes to an already established monitoring program creates a suite of problems, including data inconsistencies, both in terms of collection and analyses; loss of productivity; wasted effort; and an overall loss of program outcome achievement. However, Oakley *et al.* (2003) also noted that some changes were inevitable in such programs, although detailed pre-planning should minimise the amount of change needed.

Gerrodette (1987) recognised that particular questions often arise when designing a monitoring program to detect trends. These include, what is a sufficient number of samples? How precise must the samples be? What is the probability of detecting a trend if it is present? Gerodette (1987) devised a series of statistics that calculated the probabilities to such questions, given the sampling strategy and the variables within it (e.g. number of samples). However, CSIRO (1998) recognised that the statistical power to detect change in the indicator also depends on natural variability and sensitivity to pressure of the component(s) being measured. Therefore, an understanding of the environment that will be monitored is required, again emphasising the need for baseline data (see *2.2.3 Baseline data*). With baseline data, one can determine the amount of change that needs to be detected, what sampling methods will work best in that environment, will inform choices with regards to placement and frequency of sampling, and number of samples that need collecting.

The monitoring program, and management plan, needs to recognise that conservation is a moving target (Alcaraz-Segura *et al.*, 2009). To understand the conservation needs of a system, it is necessary to use protected areas which will show changes to ecosystem functioning, in the absence of human impact, which will aid in anticipating the consequences, and managing transitions among alternative states, in areas that are impacted by anthropogenic influences. Alcaraz-Segura *et al.* (2009) showed the need for monitoring protected area networks to better understand natural variations or changes in ecosystem function. Understanding these allows changes from natural variation to be separated from changes due to anthropogenic disturbance.

The objectives of this resource condition-monitoring framework for the Pilbara and Kimberley region are to define a set of condition indicators that can be used to assess the condition of the inter-tidal and sub-tidal systems and their response to stressors. Information on condition would then be used to direct and prioritise management actions. Implicit in this approach is that condition information can be directly linked back to stressors and hence to management actions. This framework is based upon the frameworks developed by Mount (2006) and Scheltinga & Moss (2007).

3.3 Management loops

Mount (2008) provided the framework for a reporting system and management feedback loop that should be adopted in management action and reporting plans. Mount (2008) describes the components, implementation, and running of the management loop, and that report should be consulted for details. Briefly, a number of 'passes' through a managerial framework are required. The first pass utilises a suit of processes to inform the development of a monitoring program for a particular region, or objective(s). The second pass uses information gained from the first pass to set priorities and identify key assets, threats, and actions. The third pass is a review of the monitoring process, resulting in a report card outlining the progress and critique of the parameters being used within the monitoring process, providing an overall assessment of the effectiveness of the program. The effectiveness of the program is determined by comparing the program outputs to the objectives set for the program.

From the framework provided by Mount (2008), if the objectives are being achieved, then the program continues without change, repeating the passes through the managerial framework over time. If the objectives are not being achieved, then the program needs to adapt, and adopt a new strategy. This may be in the form of revised objectives; better understanding of assets, threats, etc.; revision of the methods for detecting change, or resetting trigger values of change; among others, as examples.

3.4 Indicators and complex systems

Consider the vast number of organisms that inhabit the marine environment, both in terms of number of species, and gross biomass. Then consider the linkages between all of those organisms, as well as linkages with their physical environment. Now consider that the majority of those linkages are dynamic, and in many instances, very much so. There can be no denying that marine systems are complex. This is reiterated by Ojeda-Martínez *et al.* (2009), stating that the marine system is arguably more complex than any other ecosystem, with highly interrelated processes between its physical, chemical, and biological components. This complexity gives rise to the very real problem of selecting indicators that truly reflect ecological processes and function.

Human *et al.* (2010) have shown for mangrove environments that the use of most simplistic biological measures for use as indicators are either ineffective, or provide positively misleading information regarding the apparent 'health' of mangroves. Simplistic measures often do not capture the complexity and the function of ecological processes, which are the drivers of environmental 'health'. CSIRO (1998) also warned against over interpreting results from a simple measure, which may overly simplify complex systems. The scope of any one indicator is usually limited, they should be used in suites to give a more complete picture of a system. There is danger associated with trying to combine indicators into a single index of a system, and basing decisions on that single measure (CSIRO, 1998).

In recognising this complexity, CSIRO (1998) described emergent properties of a system, and the need to understand the system as a whole, rather than individual parts. Environmental indicators are windows to highly complex and variable systems. They are tools for extracting what is critical, for synthesising multidimensional information, or integrating the influences of many processes. However, these characteristics can be a weakness. If emergent properties can be understood and measured, they are often better summaries of the state of the system than measures of individual components (CSIRO, 1998). Goodsell *et al.* (2009) also recognised that environmental changes or impacts are complex, and that establishing a direct link between the environmental state/stress and any proposed indicator is always going to be difficult.

Related to system complexity is the inherent stress that naturally occurs in some habitats. This issue has been a topic of discussion, for estuaries in particular (Elliott & Quintino, 2007; and Dauvin & Ruellet, 2009), where the 'estuarine quality paradox' has been recognised. Transitional water bodies, especially estuaries, show high spatial heterogeneity and complexity, and a high fragmentation of the habitats in the freshwater–estuarine–coastal–open marine continuum (Dauvin & Ruellet, 2009). As such, estuaries are regarded as naturally stressed environments because of the high degree of variability in their physico-chemical characteristics. However, their biota is well adapted to cope with that stress, and so these environments may be regarded as resilient because of that inherent variability; their ability to absorb stress without adverse effects (Elliott & Quintino, 2007). Elliot & Quintino (2007) and Dauvin & Ruellet (2009) found that the characteristics of natural stress in estuaries are similar to those for anthropogenic stress, therefore over-reliance on ecosystem structural features (such as diversity) used as indicators makes the detection of the anthropogenic stress more difficult. Elliot & Quintino (2007) termed this difficulty, 'the estuarine quality paradox'. The estuarine quality paradox illustrates the need to use indicators that identify ecological processes and function, and not indicators that are purely structural.

This is further complicated for the Pilbara and Kimberley region, in that the region is tropical. Present scientific knowledge is still largely insufficient to propose unambiguous indicators in answer to all the complex environmental issues arising in the tropical coastal zone. Our knowledge on environmental indicators in tropical systems is largely deficient when compared with the existing scientific background in temperate systems, demonstrating that much more scientific work is required (Fichez *et al.*, 2005; Human & McDonald, 2009; and Human *et al.*, 2010).

There are problems associated with using complex indicators. Adjeroud *et al.* (2005) used multimetric indicators that were supposed to be more sensitive to change, since they respond to several stresses. However, Adjeroud *et al.* (2005) found that several of these indicators were difficult to incorporate into long-term monitoring programs, since they generally involve expensive equipment, complex analyses, and need technical expertise to be interpreted.

While it is true that using complex indicators will increase the costs and commitment of resources to resource condition monitoring programs, not adopting such indicators is more costly in the long term. The most cost-effective indicators should be chosen and the cheapest options are not necessarily the most effective (CSIRO, 1998). Borja *et al.* (2008) found that the use of reductionistic approaches can only partially cope with ecosystem complexity that arises from their large number of components, interactions, and spatio-temporal dynamics. Inevitably, we must recognise that the whole behaves differently from the sum of its parts, and thus neither examination of a small subsystem, nor reduction to simple relationships, is an adequate and sufficient approach to understand ecosystem functioning. What happens is that specific qualities/ features/ properties emerge at the ecosystem level, and these must be related to ecosystem functioning.

3.5 Philosophy of indicator selection

For the most part, the philosophy of Goodsell *et al.* (2009) is adopted here for selecting indicators. The process of establishing the reliability of indicators must begin with clearly defined objectives. These include an understanding and clear definition of which environmental variables of the study area need to be assessed and why. The indicator must reflect the aspect of the system that is the objective of the monitoring (CSIRO, 1998; and Goodsell *et al.*, 2009). Selection of the indicator needs to be based on substantial evidence that: (i) there exists a good and consistent correlation between many levels of the environmental variable(s) of interest and any proposed bioindicators; (ii) there is a causal relationship between the variable(s) and the response of the indicator over multiple scales; and (iii) the relationship is direct and has been tested at many levels of the stressor over multiple spatial and temporal scales (Goodsell *et al.*, 2009). Goodsell *et al.* (2009) also recognised that a further challenge is to determine whether the response of a chosen indicator to a level of impact is indicative of a deleterious state for other organisms in the system. An indicator is not going to be useful for revealing the existence of a stress and its impact on assemblages if the indicator is too inert to respond. CSIRO (1998) also identify timeliness as another consideration. Data for an indicator must be available when decisions are being made.

A core set of 75 indicators was established by the Australian and New Zealand environment and conservation council (ANZECC). These were developed due to a lack of a standard set of environmental indicators used across Australia by the states and federal governments. However, virtually all the indicators were physical parameters with no biological indicators being used (Borja *et al.*, 2008). Mount (2006) provided a list of recommendations for the use of resource condition indicators and how to implement them in a monitoring program. The recommendations related to indicator usage, data management, capacity building, reporting and evaluation. Likewise, Ward *et al.* (1998) provided a comprehensive list of potential indicators to be used in the State of the Environment reporting. They provided details regarding each indicator, including a description, rationale, analysis and interpretation, monitoring design, and more. These lists should be considered only as starting points for potential indicators, which could be used to promote data compatibility between monitoring programs. Not all of these indicators however, would be appropriate for use in a monitoring program for the Pilbara and Kimberley. It is just as important to refer to the most recent literature relating to indicators when a program is being formulated, as measures of complex systems and bioindicators continue to be developed.

Gilmour *et al.* (2006) recognised that one the most important features of an indicator is that it demonstrates patterns of low unexplained variability in the absence of key stressors. An indicator that displays seasonal or temporal variability can make it more difficult to distinguish the effects of anthropogenic stressors, but will still be appropriate provided sufficient background data are collected and the patterns of natural variability are well understood (Gilmour *et al.*, 2006). The responses of potential indicators should be validated with both manipulative experiments and sampling programs in the field to ensure they are specific to the stressor of interest, or that background variation can be sufficiently controlled. Measuring and validating responses in the field is difficult, given the natural spatial and temporal variability inherent in biological systems. Thus, sampling at a range of spatial and temporal scales is vital, which requires the quantification of the responses over an appropriate time before and after the stressor has been applied, at replicate impact and control sites (Gilmour *et al.*, 2006). The findings of Gilmour *et al.* (2006) highlight that an indicator cannot be developed or tested in the absence of baseline data.

Selecting appropriate bioindicators has mostly been discussed above (see *2.4.2 Biological indicators (Bioindicators)*). Further to that discussion, DEH (2008a) recognised that a recent trend in ecological impact assessments has been to monitor assemblages of species rather than a few pre-selected "indicator" species. In essence, this means all species sampled are identified, counted and included in the analyses. This multi-indicator approach has been reiterated by Adjeroud *et al.* (2005). Adjeroud *et al.* (2005) states that monitoring surveys could be improved by selecting different and complementary indicators. Using coral reefs as an example, the variety of indicators that should include one for variation in diversity, one for estimating changes in the abundance/ cover, and one for estimating the potential for recovery (Adjeroud *et al.*, 2005).

It is imperative, that at least some of the indicators used in a monitoring program respond quickly to minor environmental changes (Anderson *et al.*, 2006). Such 'early warning' indicators are used to determine if further investigation of a change are warranted. Detection of minor changes allows time for managerial intervention to occur before a significant (and perhaps irreversible) change occurs. The objectives of a monitoring program are defeated if detection of change occurs only after significant impacts have happened. 'Early warning' indicators can be determined by performing risk assessments of the various stressors in a system and identifying those stressors that are most likely to change, given the prevailing anthropogenic impacts occurring near that environment, and determining how much change in a stressor is needed in order for a significant impact to occur (CSIRO, 1998). Baseline data is essential in such a task.

It is also apparent that there are no perfect indicators. Different species have different thresholds within a community; therefore, enough indicators need to be used within a system to detect change amongst diverse taxa, particularly if conservation of biodiversity is an objective of the monitoring. It is necessary to use a suite of indicators that are complimentary to each other, and to the system, over multiple spatial and temporal scales. The suite of indicators should cover the majority of the ecological processes and functions that occur within a system. At the least, enough indicators should be chosen that will monitor those processes and functions that have been identified as being at high risk of change (CSIRO, 1998; Adjeroud *et al.*, 2005; Fichez *et al.*, 2005; Coates *et al.*, 2007; Courrat *et al.*, 2009; and Lucrezi *et al.*, 2009).

Baseline data is essential in determining what indicators are appropriate for any given monitoring program. However, CSIRO (1998) recognised, given that raw data are often expensive to collect, both existing and new data can be used. So it is important for indicators to make use, where possible, of all available data, even if collected for other purposes.

Finally, it is important to recognise the ramifications of the choice of indicators used to assess natural resource condition. Mount (2006) states that indicators are only a part of what is needed to obtain information about environmental resource condition. It is also necessary to carefully identify what question you are seeking to answer and then match the indicators to that question. Factors that need to be considered in indicator selection, besides their environmental context are (Mount 2006):

- Interpretation and reporting transforms monitoring data into information and knowledge that has meaning for resource managers.
- There is no "final" set of indicators, and the need to monitor is constantly evolving.
- Unless there is a commitment to long term data collection and storage, the use of indicators is futile.
- A data management infrastructure is essential.
- Consistency of data sets needs to be maintained as much as possible.
- There needs to be some infrastructure for setting data standards, data storage and retrieval.

3.5.1 Indicator selection criteria

Somewhat paradoxically perhaps, this discussion begins by listing criteria that should not be used when selecting indicators. Conventionally, the following have been included as criteria for indicator selection: ease of data collection; ease of data analysis; and low financial cost. The argument put forward here is that, whereas these are ideal properties of an indicator, the preceding sections of this report make it evident that such properties should not be used as criteria for indicator selection. Indicators that are selected using these criteria are mostly ineffective for detecting change, especially in complex systems such as those being considered here, and are therefore unlikely to be cost effective. If monitor programs are sincere about detecting environmental change and intervening before irreversible environmental damage occurs, then these criteria contradict and compromise resource condition monitoring program aims and objectives from the outset.

The following criteria have been compiled from multiple sources (Kabuta & Laane, 2003; Scheltinga *et al.*, 2004; Gilmour *et al.*, 2006; Mount, 2006; Alcaraz-Segura *et al.*, 2009; Goodsell *et al.*, 2009; Lucrezi *et al.*, 2009; and Human *et al.*, 2010):

- An indicator must have a distinct relationship with the process.
- An indicator needs to be responsive to change in the system.
- An indicator must have a predictable response to change and accurately reflect what is happening in the system.
- An indicator needs to be sensitive to particular threats (stressors) that have been identified for the system.
- An indicator should be largely insensitive to expected sources of interference.
- The indicator must be suited to the spatial scale.
- The response time of an indicator must be appropriate for the temporal scale of the environmental processes and functions that occur within the system.
- 'Early warning' indicators operate on relatively short temporal scales, so that major impacts are pre-empted rather than documented.
- An indicator must be accessible for year round sampling, if not, seasonal factors (or other factors) need to be accounted for accurately.
- The indicator will allow reporting on change.
- The indicator has an agreed or robust methodology.
- The indicator is compatible with other studies.
- The indicator is usable over a range of spatial and temporal scales.
- The indicator can be used to distinguish between anthropogenic impacts and natural variation.
- Quantitative targets and baseline values can be assigned to the indicator.

3.6 Trigger/ threshold values

For an indicator to be effective, a trigger or threshold value needs to be assigned to it. A trigger/ threshold value is a value attributed to a measure, which if met or exceeded, warrants further investigation of that change. A trigger value should indicate change in a system that is not yet significant. Conversely, a trigger value should not be so conservative that unnecessary effort is committed to investigating a change that will not lead to significant change in the system, or a change that is due to natural variation. Therefore, one needs to identify a target value.

In order to find the compromise between too conservative and inert trigger values, Gilmour *et al.* (2006) recognised the need to create stress response curves for each indicator. Gilmour *et al.* (2006) also recognised that all thresholds need to be time-integrated. The severity of a response is not only determined by the amount of exposure, but also by the duration of exposure. A fundamental requirement to setting targets is the need for baseline information. Baselines should be quantified as fully as possible, and should relate to trends going back over several years rather than a single point-in-time measurement (Scheltinga *et al.*, 2004). These points further highlight the critical need for baseline data and long term data collection.

It is recommended here that when trigger values are being assigned that they must be set relatively conservatively, i.e. that the system is not so impacted that recovery is not possible. If trigger values are found to be set too conservatively, they can be adjusted over time, consistent with the data gained through the monitoring program, so that they are less so. It is prudent to use the precautionary principle here, as there have been cases where indicators were not set conservatively enough and recovery is taking too long. This is particularly true in many of the world fisheries (Dulvy *et al.*, 2000; Environment Australia, 2002; Baum *et al.*, 2003; Cavanagh *et al.*, 2003; Myers & Worm, 2003; and Baum & Myers, 2004).

3.7 Reporting

CSIRO (1998) state that indicators need to deliver information of use to managers, or they won't respond. Few managers have the time or inclination to understand complex or obscure indicators. The science behind an indicator may be complicated; so, those developing it must provide clear guidance about its' meaning and its levels of uncertainty. However, reporting systems have been used less consistently than indicators. A Data Reporting System (DRS) was developed for State of the Environment (SoE) reports, however, the uptake of a uniform reporting system has been slow (Borja *et al.*, 2008).

3.7.1 Setting RCM target metrics

CSIRO (1998) define targets as specified levels or ranges for a measurable quantity that a group aims to achieve that may be adopted by governments, industry, organisations, or individuals. Targets are policy tools, but may have a scientific base. A trigger/ threshold value is the value for an indicator that has some defined environmental significance in the functioning of the natural system, whereas targets have a basis in policy, and reflect human values.

3.7.2 Score cards

For a resource condition monitoring program to be effective, effective and efficient reporting systems must be in place to deliver key messages to managers. These key messages should include basic information about the condition of the resource (excellent condition; good condition; fair condition; poor condition; very poor condition), the pressures on the resource (extreme pressure, high pressure, moderate pressure, low pressure, negligible pressure), trend of the resource (improving; stable; declining), and what actions are needed (urgent action required; further investigation required; review of methodologies required; no intervention needed), as examples.

An effective means of communicating these key messages to managers is through the use of colour coded score cards, such as those described by Scheltinga & Moss (2007). Scheltinga & Moss (2007) offered a point scoring scale to reflect the status of the key message being reported. Table 1 shows a colour coded score card for resource condition, and Table 2 shows a colour coded score card for intensity of pressure on a system, as examples (adapted from Scheltinga & Moss, 2007).

Table 1. Example of a colour coded score card indicating resource condition (adapted from Scheltinga & Moss, 2007).

Resource Condition	
Scoring category	Condition of the system
1	Excellent condition
2	Good condition
3	Fair condition
4	Poor condition
5	Very poor condition

Table 2. Example of a colour coded score card indicating pressure intensity on the system (adapted from Scheltinga & Moss, 2007).

Pressure Intensity	
Scoring category	Pressure level on the system
1	Negligible pressure
2	Low pressure
3	Moderate pressure
4	High pressure
5	Extreme pressure

The scoring category is structured so that the most urgent key messages receive the highest score, and scores between tables are additive. For example, lets assume that an environment is in very poor condition (score = 5) but has negligible pressure exerted on it (score = 1), then the overall score is 6 (out of 10) for that environment. If an environment is in poor condition (score = 4) and has high pressures exerted on it (score = 4), then the overall score is 8 (out of 10), making it a higher action priority than the preceding example.

Colour coded score cards can be presented to managers for the various habitats, environments, ecological processes, ecological functions, regions and efficiently communicate areas that require management action, and communicates just as effectively, those areas of the monitoring program that do not require further action. Finally, a score card assessing the monitoring programs achievements and outcomes against the objectives of the project can be used to assess the overall performance of the monitoring program.

4.0 Motivating for monitoring funding

The author affirms that it is time for funding bodies and decision makers to recognise that resource condition monitoring of marine and coastal systems requires complex data collection and analyses, brought about from the inherent complexity of the system. This will inevitably result in higher costs in terms of finance, time investment, and the allocation of resources. To continue insisting on the use of easily collected and analysed measures, in light of recent cumulating evidence pointing to the inefficiencies of such methods, is pure ignorance on the part of the funding bodies and decision makers. Mounting evidence clearly shows that complex systems cannot be effectively monitored using simplistic measures.

In justifying the increased costs of such monitoring programs, funding bodies and decision makers should be referred to the value of the environment they are protecting. Parties planning monitoring programs should not initiate funding requests with a dollar value. Instead, calculate the approximate worth of the environment/ habitat/ system to be monitored based on the human activities that occur within, or could possibly affect it. This estimated value is likely to be sizeable, conservatively in the region of tens of millions of Australian dollars. A small percentage of this value should be requested for monitoring purposes for the preservation of its current value for future financial investment.

To illustrate this concept, consider the marine environment of the Pilbara region. The Gorgon project alone is valued at AU$64.3 billion. Add to this all other commercial uses of the region, including other gas and mining ventures, commercial fishing, and tourism. Now add recreational fishing, boating, beach-going, etc. A conservative value of AU$70 billion could easily be argued for the worth of the region, not including aesthetic value. To request one hundredth of a percent (0.01%) of that value would not appear a significant request at face value, however, would result in AU$7 million dollars for monitoring. This would be an ample amount of funding for a monitoring program, and yet would help secure an environment worth ten thousand times more than the monitoring costs.

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SECTION B – Environmental Stressors and Resource Condition Indicators

7.0 Explanatory notes for Section B

This section is adopted from the *Users' guide for Estuarine, Coastal and Marine indicators for regional NRM monitoring* (Scheltinga *et al.*, 2004), with some minor amendments, to promote consistent and compatible usage of frameworks of this nature. A brief overview of potential resource condition indicators (RCI's) is provided here, whereas a comprehensive overview of the RCI's are provided in Scheltinga *et al.* (2004).

In the proceeding pages, various stressors are presented. A brief description of the stressor is provided. For each stressor, lists are provided for the potential causes of change to the stressor, and potential signs of a changed stressor. Also provided for each stressor are a range of potential resource condition indicators (RCI) that could be used to monitor change in that stressor. A strategic management/ monitoring model is also provided for each stressor. This model identifies the current managing agency, the body charged with primary monitoring of the stressor, as well as other parties involved in the monitoring of that stressor.

After the stressors have been introduced, the potential RCI's listed for the stressors are described in detail (based on Scheltinga *et al.*, 2004). It is important to note that the RCI's listed for a given stressor are suggested RCI's only. Some RCI's may not be appropriate for certain stressors in some environments. The choice of RCI's will ultimately depend on the objectives and aims of the monitoring program, the appropriateness and effectiveness of the RCI in a given system, as well as the availability of newly developed RCI's published in the scientific literature. The RCI selection process is covered in detail in Section A of this report.

Institutional abbreviations are provided in the list of abbreviations at the beginning of this document.

Potential **causes** of change to stressor	Potential **signs** of changed stressor
• Boat wash (causing bank and beach erosion) • Dredging and extractive operations (sand and gravel mining) • Episodic and large scale events (drought, floods, storms, cyclones, bushfires) • Filling of floodplains or wetlands • Groundwater dynamics (changed movement of water into or out of coastal waters) • High density human population • Increased human population • Increased human visitation • Modification of natural drainage pathways • Reclamation • Recreational off-road vehicles causing loss of coastal vegetation • Removal of habitat (e.g. for buildings, construction, foreshore development, roads and bridges, marine facilities and infrastructure, aquaculture, urbanisation, etc.) • Sedimentation (change in sediment loads or distribution) • Shading by aquaculture and other infrastructure causing loss of seagrass and other bottom vegetation • Tourism • Trawling • Uncontrolled coastal access (especially offroad vehicles) • Weapons testing/ use	• Beach and foreshore sediment erosion and accumulation • Biodiversity decreased • Biota (plants and animals) lost/ disturbed • Coastal erosion • Coastal vegetation loss • Coastal wetlands loss • Dune vegetation cover decreased • Estuarine riparian vegetation cover decreased • Foreshore vegetation decreased • Habitat loss or disturbance • Nuisance growth of aquatic plants or algae • Poor water quality: associated with habitat removal; turbidity • Seafood catch or stock (changed) • Shorebirds disturbed/ numbers decreased • Species (plant or animal) composition (changed or species lost) • Turbid water • Visual amenity decreased

Stressor

Habitat

Removal, loss or disturbance of large areas of habitat, such as those listed in the 'Key habitats' indicator profile

Stressor

Ecosystem condition indicators		Habitat extent indicators
Physico-chemical	**Biological**	
• None recommended	• Animal or plant species abundance (species dependent on the habitat removed/ disturbed)	• Animal or plant species abundance (species dependent on the habitat removed/ disturbed) • Extent/ distribution of key habitat types

Strategic Management/ Monitoring Model

Current Managing Agency	→	Primary Monitoring	→	Other Research
DEC, DoF		DEC		AIMS, CSIRO, UWA, WAM

Potential **causes** of change to stressor	Potential **signs** of changed stressor
• Aquaculture • Artificial opening or closing of estuary mouth • Breakwaters • Canals • Climate change/ global warming (changed rainfall patterns, changing ocean currents, sea level rise, southern oscillation, increased air temperature) • Draining of wetlands and billabongs • Dredging • El Niño/ La Niña • Entrance modification • Environmental flows (changed) • Episodic and large scale events (drought, floods, storms, cyclones, bushfires) • Extraction (mining) • Groundwater dynamics (excess caused by artificial ponds and lagoons, changed movement of water into or out of coastal waters) • Groynes • Industrial and municipal discharge (hot or cold water) • Marinas, harbours, wharves and ports • Nuisance growth of aquatic plants (blocking waterways) • Retention walls/ training walls/ levees • Saltwater intrusion (movement of salt water into lower concentration/ non-saltwater environment) • Sea walls • Spits • Urbanisation • Water barriers • Water flows and frequency of floods from catchment water changed from natural by dams, barriers, water extraction, levees, impoundments and weirs, increased hard surfaces, land cover • Water-current pattern/ water mixing (changed)	• Algal blooms (change in frequency and type) • Animal and plant physiology (changed) • Animal behaviour (changed) • Anoxic and hypoxic events (due to high algal growth followed by death of algae, isolated - altered oxygen solubility) • Beach/ foreshore erosion and accumulation • Biodiversity decreased • Biota (plants and animals) lost/ disturbed • Biota distribution (changed) • Biota reproduction rate (changed) • Coastal currents (changed) • Coastal erosion • Coastal floodplains lost • Coral bleaching • Current and wave patterns (changed) • Erosion and sedimentation (deposition) rates (changed) • Estuary mouth open/ close frequency (changed) • Eutrophication • Habitat lost/ disturbed • Habitat lost/ disturbed through erosion • Hypersalinity • Hyposalinity • Impeded fish/ animal passage • Microbial processes (changed processes or rates) • Nuisance growth of aquatic plants or algae • Poor water quality associated with changed flushing rates: anoxia, hypoxia, turbidity, nutrients, elevated water temperature, elevated chlorophyll concentrations • Riparian zone (changed) • Seafood catch or stock (changed) • Sediment accumulation through changed sediment transport or loads • Species (plant or animal) composition (changed or species lost) • Stratification of waters (change in mixing rates) • Turbid water • Water depth (changed) • Water stratification (thermoclines; poor water column mixing) • Water temperature (changed) • Wetlands vegetation lost

Stressor

Hydrodynamics

Freshwater influx – changes to pattern/ amount of catchment waters entering estuarine and coastal systems

Oceanographic – changes to local patterns of waves, currents or tidal exchange

Temperature – local and surface water (sea, estuary) temperature

Stressor

Ecosystem condition indicators		Habitat extent indicators
Physico-chemical	**Biological**	
• Erosion rate • Estuary mouth opening/ closing • Salinity • Sedimentation rate • Turbidity • Water temperature • Water-current patterns	• Algal blooms • Chlorophyll a • Coral bleaching • *For intertidal sand/ mudflat:* benthic microalgae biomass • *For rocky shores, rocky reef and coral reef:* biomass, or number per unit area, of macroalgae • *For seagrass and mangroves:* biomass, or number per unit area, of epiphytes	• None recommended

Strategic Management/ Monitoring Model

Current Managing Agency	Primary Monitoring	Other Research
DEC, DoF	DEC	AIMS, CSIRO, IMOS, UWA

Potential **causes** of change to stressor	Potential **signs** of changed stressor
• Debris from commercial fishing • Debris from recreational fishing (e.g. fishing line, nets, bait bags) • Debris from terrestrial sources washed into waterways • Debris from unlawful littering • Dumping cars/ boats etc. as artificial reefs • Dumping from international shipping and fishing fleets • High density human population • Increased human population • Increased human visitation • Rubbish dumping • Tourism	• Biota (plants and animals) lost/ disturbed • Presence of litter • Tangling of animals and plants in litter (e.g. plastic bags, fishing line) • Visual amenity decreased

Stressor

Litter

Human made rubbish/ debris

Stressor

Ecosystem condition indicators		Habitat extent indicators
Physico-chemical	**Biological**	
• Presence/ extent of litter	• Animals killed or injured by litter (entanglement, starvation, suffocation)	• None recommended

Strategic Management/ Monitoring Model

Current Managing Agency	→	Primary Monitoring	→	Other Research
DEC		DEC		

Potential **causes** of change to stressor	Potential **signs** of changed stressor
• Aquaculture escapees • Aquaculture production • Aquarium releases (plant or animal) • Dumping garden refuse/ rubbish • Escape of weeds from gardens, etc. • Release/ transport of pest species • Transport of pests attached to boat hulls, fishing/ diving gear/ equipment, and other infrastructure • Transport of pests in ballast water • Transport of pests via dredge spoil	• Algal blooms of pest species • Animal (fish/ macrobenthos) kills • Animal behaviour (changed) • Biodiversity decreased • Biodiversity of coastal vegetation (including terrestrial vegetation) decreased • Biota (plants and animals) lost/ disturbed • Habitat lost/ disturbed • Human health problems (infections, gastro, viruses, disease, etc.) • Monoculture of pest vegetation • Nuisance growth of aquatic plants or algae • Paralytic shellfish poisoning and other phytoplankton toxins • Pest outbreaks • Seafood catch or stock (changed) • Species (plant or animal) composition (changed or species lost)

Stressor

Pests

An invasive organism that is detrimental to an ecosystem

Stressor

Ecosystem condition indicators		Habitat extent indicators
Physico-chemical	**Biological**	
• None recommended	• Pest species (number, density, distribution)	• None recommended

Strategic Management/ Monitoring Model		
Current Managing Agency →	**Primary Monitoring** →	**Other Research**
DoF	DoF	

Potential **causes** of change to stressor	Potential **signs** of changed stressor
• Coastal erosion • Diffuse sources: catchment run-off (rural and urban) • Discharge of primary treated sewage (contains sediments) • Dredging, trawling: resuspension of sediments • Dumping of dredged material • Dune vegetation cover decreased • Episodic and large scale events (drought, floods, storms, cyclones, bushfires) • Extraction (mining) • Point sources: industrial discharge, sewage treatment plant (primary treated) discharge, dumping of wastewater • Resuspension of sediments; higher - caused by changed water flows or erosion • Sediment movement changed - from changed hydrodynamics • Shipping movement through shallow waters • Soil disturbance in coastal zone due to development • Urban development causing loss of coastal habitat and increased erosion • Water impoundments cause changes in sediment loads from catchment	• Abundance of filter feeder and grazing animals (changed) • Animal (sessile benthic) kills • Animal behaviour (changed) • Beach/ foreshore erosion and accumulation • Biodiversity decreased • Biota (plants and animals) lost/ disturbed (smothering, physical abrasion of gills and behavioural changes) • Boating access decreased (shallow banks/ flats) • Bottom vegetation lost by smothering or lower light availability • Erosion and sedimentation (deposition) • Habitat lost/ disturbed (smothering) • Light penetration (changed) • Poor water quality: turbidity • Primary aquatic plant productivity (changed) • Seafood catch or stock (changed) • Seagrass cover decreased caused by loss of light availability • Sediment grain size distribution (changed) • Species (plant or animal) composition (changed or species lost) • Turbid water • Visual amenity decreased • Water depth (changed)

Stressor

Sediment quality

Change to load, distribution/ movement patterns, settlement/ resuspension rates, grain size of suspended or settled sediments

Stressor

Ecosystem condition indicators		**Habitat extent indicators**
Physico-chemical	**Biological**	
• Erosion rate • Sedimentation rate • Turbidity	• Animal or plant species abundance (loss of light dependent biota, loss of sessile biota)	• Extent/ distribution of beach and dunes • Extent/ distribution of intertidal mudflats • Seagrass depth range

Strategic Management/ Monitoring Model

Current Managing Agency	→	**Primary Monitoring**	→	**Other Research**
DEC, DoF		DEC, DoF		AIMS, CSIRO

Potential **causes** of change to stressor	Potential **signs** of changed stressor
• Anchor damage • Aquarium species collection • Bait collection • Boat strike • Commercial fishing (including by-catch, illegal practices) • Competition by pests (plants or animals) • Dredging • Episodic and large scale events (drought, floods, storms, cyclones, bushfires) • Extraction (mining) • Fisheries by-catch • High density human population • Increased human population • Increased human visitation • Powerboat and jet ski usage • Recreational fishing (including by-catch, illegal practices) • Shading by aquaculture and other infrastructure causing loss of seagrass and other bottom vegetation • Shark nets/ drum lines • Seismic survey • Shell collection • Tourism • Trawling • Turbid water causing lowered light availability to plants	• Animal behaviour (changed) • Biodiversity decreased • Biota (plants and animals) lost/ disturbed • Biota distribution (changed) • Biota reproduction/ regeneration rate (changed) • Fish size distributions (changed) • Seafood catch or stock (changed) • Species (plant or animal) composition (changed or species lost) • Visual amenity decreased

Stressor

Species Composition

Removal, loss or disturbance of individual organisms of a specific species, not areas of habitat

Stressor

Ecosystem condition indicators		Habitat extent indicators
Physico-chemical	**Biological**	
• None recommended	• Animal or plant species abundance • Death of marine mammals, reptiles, and endangered sharks, caused by boat strike, shark nets or drum lines	• None recommended

Strategic Management/ Monitoring Model

Current Managing Agency	→	Primary Monitoring	→	Other Research
DEC, DoF		DEC, DoF		AIMS, CSIRO, MU, UWA, WAM

Potential **causes** of change to stressor	Potential **symptoms** of changed stressor
• Aquaculture - accidental culture and release of pathogens • Boat engine/ generator emissions • Boating and infrastructure antifoulants (e.g. TBT) • Diffuse sources: catchment run-off (rural and urban) • Diffuse sources: catchment run-off, storm water and land management practices (animal and human wastes) Imported feed for aquaculture • Dumping (regulated and illegal) • Episodic and large scale events (drought, floods, storms, cyclones, bushfires) • Harmful algal blooms • Insect control chemicals • Petrochemical spills • Point sources: industrial discharge, sewage treatment plant discharge, dumping of toxicants or wastewater • Sewage discharge from vessels • Sewage treatment plant discharge • Shipping accidents • Stormwater discharge of catchment water • Vegetation control chemicals • Toxicant spills • Weapons testing/ use	• Animal disease/ lesions/ mutations/ aberrant growth and reproduction/ neurological/ respiratory dysfunction • Animal (fish/ macrobenthos) kills • Animal and plant physiology (changed) • Animal behaviour (changed) • Biodiversity decreased • Biota (plants and animals) lost/ disturbed • Fisheries productivity decreased • Habitat lost/ disturbed • Human health problems (skin irritations, infections, gastro, viruses, disease, etc.) • Imposex (development of male sex organs in female gastropods) • Poor water quality: high bacteria/ pathogen counts/ toxicant levels • Seafood catch or stock (changed) • Shellfish/ fisheries closures • Species (plant or animal) composition (changed or species lost)

Stressor

Toxicants

Anthropogenic - loads, concentrations or bioavailability of pesticides, herbicides, organics, oils, hydrocarbons, metals, metalloids, organometallics, radiation, other toxic chemicals and contaminants

Biological - bacteria, viruses, protozoans or fungi which cause disease

Stressor

Ecosystem condition indicators		**Habitat extent indicators**
Physico-chemical	**Biological**	
• Toxicants in biota • Toxicants in the sediment • Water soluble toxicants in the water column	• Animal kills • Occurrence of imposex • Targeted pathogen counts	• None recommended

Strategic Management/ Monitoring Model

Current Managing Agency	→	**Primary Monitoring**	→	**Other Research**
DEC, DoF		DEC, DoF		

Potential **causes** of change to stressor	Potential **signs** of changed stressor
• Algal blooms and nuisance growth of aquatic plants • Diffuse sources: catchment run-off (rural and urban) • Disturbance of actual or potential Acid Sulphate Soils (ASS) - acid sulphate run-off • Episodic and large scale events (drought, floods, storms, cyclones, bushfires) • Extraction (mining) • Groundwater dynamics (changed movement of water into or out of coastal waters) • Groundwater movement of hypersaline water • Industrial discharge • Large water release from water impoundments in catchment • Localised freshwater input (large storm water, industrial discharge, etc.) • Point sources: industrial/ aquaculture discharge, sewage treatment plant discharge, sewage overflows, aquaculture discharge/ waste, dumping of wastewater or organic matter • Reduced freshwater input with high evaporation • Salt or saltwater input increased • Sediment delivery to estuary or coastal waters (changed)	• Acidification of water • Algal blooms (change in frequency and type) • Animal (fish/ macrobenthos) kills • Animal and plant physiology (changed) • Animal lesions and disease • Anoxic and hypoxic events (due to high algal growth followed by death of algae and/ or increased oxygen demand) • Benthic microalgae biomass (changed) • Biodiversity decreased • Biota (plants and animals) lost/ disturbed • Choking algal growth (and loss of amenity) • Coral bleaching • Decay of infrastructure • Eutrophication • Fish kills (due to toxic algal blooms) • Habitat lost/ disturbed • Hypersalinity • Hyposalinity • Intertidal or subtidal algae (changed amount, species) • Low/ high pH • Nuisance growth of aquatic plants or algae • Phytoplankton blooms • Plankton biodiversity decreased (e.g. due to noxious or toxic blooms) • Poor water quality: anoxic or hypoxic conditions, decreased salinity or conductivity elevated salinity or conductivity, increased nutrients • Primary aquatic plant productivity (changed) • Reduced light penetration from plant growth (algal blooms, macroalgae, macrophytes) • Release of metals from infrastructure • Seafood catch or stock (changed) • Seafood closures or contamination of seafood by toxins from toxic algae • Seagrass loss (due to reduced light availability from algal blooms and epiphytes) • Species (plant or animal) composition (changed or species lost)

Stressor

Water Quality

Hypersalinity – localised or point source discharge of salt or salty water, increased evaporation rates, decreased freshwater input

Hyposalinity – localised or point source discharge of freshwater (not diffuse catchment runoff)

Nutrients – change to load, bioavailability, concentrations of nutrients

Organic matter – carbon based material derived from plants or animals (e.g. decaying plant matter or animal wastes). It can be in either dissolved or particulate forms

pH – acidity or alkalinity of water

Stressor

Ecosystem condition indicators		Habitat extent indicators
Physico-chemical	**Biological**	
• Dissolved oxygen • pH • Salinity • Total nutrients in the sediments • Total nutrients in the water column	• Algal blooms • Animal disease/ lesions • Animal kills • Chlorophyll a • Coral bleaching • For intertidal sand/ mudflat: benthic microalgae biomass • For rocky shores, rocky reef and coral reef: biomass, or number per unit area, of macroalgae • For seagrass and mangroves: biomass, or number per unit area, of epiphytes	• Extent/ distribution of subtidal macroalgae

Strategic Management/ Monitoring Model

Current Managing Agency	→	Primary Monitoring	→	Other Research
DEC, DoF, DoW		DEC, DoF, DoW		AIMS, CSIRO, MU

7.1 Indicator: Algal blooms

Definition

This indicator reports the frequency of algal blooms (macroscopic and microscopic algae) in estuarine, coastal and marine waters.

Rationale

Algal blooms are a serious coastal problem with consequences for seafood sales, ecosystem and human health, tourism and recreation. Although algal blooms can occur naturally and provide food for other organisms, they may have harmful effects on the system. Some blooms can be toxic to aquatic organisms and cause allergic responses in sensitive people. Blooms of toxic species (e.g. toxic cyanobacteria and dinoflagellates) can produce toxins that harm grazing species and bioaccumulate up the food chain. In addition to the health issues, blooms can cause bad odours and affect visual amenity, thus having major detrimental consequences for tourism. The decomposition of normally harmless blooms (e.g. some cyanobacteria, diatoms, and macroalgae) can result in decreased dissolved oxygen resulting in large scale death of aquatic organisms (e.g. fish kills). Other blooms (e.g. some diatoms, dinoflagellates and raphidophytes) are not toxic but can still be harmful due to physical characteristics (e.g. spines) that affect the gills and tissues of animals. Blooms can also affect pH levels and turbidity (resulting in decreased light penetration with its associated problems for other plants). For a detailed explanation of what factors cause algal blooms, the significance of these blooms, and which waterways are most susceptible see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Water quality	<$30	Moderate Moderate	Moderate Moderate

Links to issues

- Decreased environmental flows
- aquatic plants or algae (and loss of amenity)
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients, increased turbidity, low dissolved oxygen (increased oxygen demand)
- Toxicity caused by toxic algal blooms

Monitoring locations and frequency

The monitoring of this indicator is opportunistic and as such it is not linked with any set monitoring location or frequency. Areas which are most susceptible to algal blooms should be monitored. As estuaries link the land to the sea, estuarine and coastal waters are good monitoring locations, as much of the eutrophication occurring here often the result of land-based activities. Nutrient input into warm, calm and stratified conditions (low flushing/ mixing rates and low turbidity) occurring in enclosed bays and systems with small tides (mean tidal range <2m) are also more likely to result in algal blooms. Conversely, blooms seldom occur in well-flushed (i.e. large freshwater inflow, high tidal exchange) or highly turbid systems. High flushing/ mixing rates dilute nutrients and microalgae densities, whereas turbidity reduces the amount of light available for algal growth.

Data measurement methods

Detailed monitoring methods for algal blooms can be found in numerous publications including: the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), guidelines for State of the Environment reporting (Ward *et al.*, 1998), and other scientific publications.

Algae concentrations often become so dense that blooms may appear as streaks, slicks or scums floating on the water, or as greenish, brownish or reddish colourations of the water. Whenever a bloom is suspected visually, algae concentrations must be measured for confirmation. Chlorophyll a (see chlorophyll a indicator profile) is a good indicator of algal biomass. The monitoring of water temperature, nutrient concentrations and chlorophyll a may be useful in the early warning of blooms.

Data analysis and interpretation

Within each system changes in the frequency of blooms should be assessed using statistical analyses to summarise change. The frequency of algal blooms is generally considered to be related to nutrient loads coming into the system from land-based sources. Although system hydrodynamics (flushing and mixing), water temperature and turbidity (i.e. light penetration) also influence the occurrence of blooms, however, all things considered, the frequency of algal blooms should decrease with decreased nutrient loads entering the system.

It is important to try and correlate the occurrence of algal blooms to nutrients, hydrodynamics and/ or turbidity changes to determine if changes are natural or due to human impacts. The Department of the Environment and Heritage (Australian Government) provides protocols for State of the Environment reporting on algal blooms (Ward *et al.*, 1998). The effect of nutrient load and environmental conditions on chlorophyll a concentrations (a good indicator of algal biomass) in different types of waterways can be examined using the Simple Estuarine Response Model II (SERM II) (CSIRO, 2003).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. http://www.deh.gov.au/water/quality/nwqms/volume1.html

ANZECC/ ARMCANZ, 2000b. Australian Guidelines for Water Quality Monitoring and Reporting. http://www.deh.gov.au/water/quality/nwqms/monitoring.html

CSIRO. 2003. Simple Estuarine Response Model II. http://www.per.marine.csiro.au/serm2/index.htm

National Land and Water Resources Audit. 2002. Australian Catchment, River and Estuary Assessment 2002. Volume 1, 192 pp. National Land and Water Resources Audit, Commonwealth of Australia, Canberra.

(OzEstuaries). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Ward, T., Butler, E. and Hill, B. 1998. Environmental indicators for national state of the environment reporting – Estuaries and the sea. Australia: State of the Environment (Environmental Indicator Reports). 81 pp. Department of the Environment; Canberra. http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

Waterwatch. http://www.waterwatch.org.au/

Waterwatch WA. http://www.ribbonsofblue.wa.gov.au/information/ribbons-of-blue-/-waterwatch-wa-data-collection.html

Water and Rivers Commission (WRC). http://www.nwc.gov.au/www/html/220-rivers--wetlands.asp

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Biomass – The total weight of all living organisms in a biological community or of a particular species/ group.

Cyanobacteria – Photosynthetic bacteria also called blue-green algae.

Diatom – Microscopic algae with cell walls made of silicon.

Dinoflagellate – Microorganisms with both plant-like and animal-like characteristics, usually classified as protozoans having two lash-like structures (flagella) used for locomotion.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Raphidophyte – Microscopic algae capable of producing environment toxic which may bioaccumulate up the food chain.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.2 Indicator: Animal disease/ lesions

Definition

This indicator reports the occurrence of animal disease/ lesions in estuarine, coastal and marine systems.

Rationale

Disease causing bacteria and pathogens are naturally present in estuarine, coastal and marine systems. Generally, healthy animals show no ill effects of their presence unless there is a change in a predisposing environmental factor such as overcrowding, nutrition or water quality. Poor environmental condition will stress animals, resulting in a decline in the ability of their immune systems to protect them from disease. Red spot disease (epizootic ulcerative syndrome) is an example of a pathogen that affects fish assemblages that are stressed by unfavourable environmental factors. Low pH (acidic waters) increases the susceptibility of fish to this fungal disease. Sublethal exposure to acidic runoff can result in physical damage to the gills, skin and eyes of fish, with skin damage increasing its susceptibility to fungal infections.

The prevalence of lesions are either exclusively or significantly increased in fish from contaminated sites. Therefore, a change in the occurrence rate of animal disease/ lesions is an indicator of a change in an environmental stressor such as pH or toxicants.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Water Quality	>$100	Easy	Moderate

Links to issues

- Animal disease/ lesions/ mutations/ aberrant growth and reproduction/ neurological and respiratory dysfunction
- Animal kills
- Aquaculture - accidental culture and release of pathogens
- Disturbance of actual or potential Acid Sulphate Soils (ASS) - acid sulphate run-off
- Point sources: sewage treatment plant discharge, dumping of toxicants or wastewater
- Poor water quality: high bacteria/ pathogen counts, high toxicant levels, low/ high pH

Monitoring locations and frequency

Animal disease/ lesions occur sporadically and as such, are monitored where and when they occur, or at locations where environmental stressors are known/ thought to be impacting on the animals present.

Data measurement methods

Animals thought to be affected by disease, (see data analysis and interpretation below) should be collected and sent to a diagnostic laboratory to identify the cause of the disease. It is essential that samples are collected live or correctly preserved to allow accurate diagnosis of the disease. A minimum of three live/ preserved animals that show clear signs of disease are needed. Animals that are freshly dead may be suitable for diagnostic purposes. However, not long after death the animal's tissues rapidly breakdown and any parasites (which may be the cause of the lesions) die or drop off the host. A further complication is that isolation of the original bacteria that caused the disease may be difficult as secondary bacteria will rapidly colonise the body upon death, overgrowing the original bacteria.

Collected samples should be placed in sealed containers and stored in the fridge or on ice for transport and analysis within two days. If possible, samples can be transported live, although diseased animals may not survive for long following capture. Samples should not be frozen unless absolutely necessary. Freezing destroys tissue structure and makes bacterial isolation less reliable. Along with the diseased animal sample and general site information (location, time, date, name, etc.), the following information should be provided to assist in making the correct diagnosis:

- an estimate of the area affected
- weather conditions (including the previous 24 hours)
- the type (species) affected and an estimate of their number and size

- if dead animals are also present
- how the animals are behaving and a description of any observed lesions
- if any unusual or abnormal/ foreign materials were present (e.g. chemical slicks, rubbish, etc.)
- any other relevant information (e.g. industries or agricultural activities occurring nearby, water colour, etc.)
- any water quality data collected previously
- Water and sediment samples from the site should also be taken for chemical analysis.

Data analysis and interpretation

Following are lists of the types of physical and behavioural changes that may be observed and will indicate the occurrence of disease in animal populations.

General indicators of the possible presence of disease are:

- sudden mass mortality
- constantly high or increasing mortality over time (i.e. mortality above normal levels)
- fish congregating at the surface
- change in water appearance
- change in smell (algae, hydrogen sulfide, ammonia)
- increased numbers of predators or scavengers

Specific indicators of the presence of disease in fish are:

- behavioural signs – anorexia; lethargy; erratic swimming, porpoising, spiraling, or bobbing; flashing and rubbing; loss of equilibrium; gulping at water surface
- clinical signs
  - gill lesions – bleeding; colour change; swelling; adherent debris; areas of tissue destruction or loss of gill filaments; white spots
  - skin lesions – abrasions, erosions, or ulcers; excessive mucus or dryness; haemorrhage; areas of discoloration; perforations; white spots; woolly or cottony appearance
  - swollen belly with free fluid
  - bulging eyes
  - physical deformities

A change in the occurrence rate of animal disease/ lesions is an indicator of a change in an environmental stressor such as pH or toxicants. For example, exposure of fish to acidic water and toxic heavy metals associated with disturbed acid sulfate soils damages their skin and gills, increasing their susceptibility to fungal infections such as red spot disease.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality, and/or animal health monitoring.

References and further information

Johnson, L.L., Stehr, C.M., Olson, O.P., Myers, M.S., Pierce, S.M., McCain, B.B. and Varanasi, U. 1992. Fish Histopathology and Relationships Between Lesions and Chemical Contaminants (1987-89). Department of Commerce, National Oceanic and Atmospheric Administration, and National Marine Fisheries Service. http://www.nwfsc.noaa.gov/publications/techmemos/tm4/techmem4.htm#toc

(OzEstuaries). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. htp://www.ozestuaries.org/indicators/indicators.html

Thad Cochran, National Warmwater Aquaculture Center. Submitting Diseased Fish for Diagnostic Evaluation. http://msstate.edu/dept/tcnwac/samples.pdf

Water and Rivers Commission (WRC). http://www.nwc.gov.au/www/html/220-rivers--wetlands.asp

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

Epizootic ulcerative syndrome – Red spot disease of fish (caused by a fungus).

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.3 Indicator: Animal kills

Definition

This indicator reports the occurrence of the 'unusual' death of a relatively large number of animals, usually fish.

Rationale

Animal kills may have a natural or human related cause like anoxic and hypoxic events, infectious diseases, toxic algae and uncommon weather patterns. The frequency and magnitude of kills are relatively good indicators of biological condition and are generally believed to reflect the integrity of an estuarine, coastal or marine system. A kill is an unexpected and generally short-lived event marked by the conspicuous death of large numbers of fish (e.g. fish kill) or other organism (e.g. bird kill). Fish and bird kills in excess of one event per year are considered indicative of compromised ecosystem integrity according to criteria established during the National Land and Water Resources Audit. Fish/ bird kills was used as one determinant of ecosystem integrity in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002). Kills are caused either directly or indirectly by changes to stressors. For example, increased toxicants or changed pH can directly result in kills. Whereas, an increase in organic matter may indirectly cause kills as high amounts of organic matter may result in low dissolved oxygen (DO) – it is this low DO which actually causes the kill. Because of the variety of factors which can potentially cause kills, it is important that the actual cause is accurately determined.

Fish kills can deplete valuable stocks and render others susceptible to overfishing. A kill can also disrupt food web dynamics and the interdependencies between species. They can promote colonisation of noxious species and eliminate species essential to the healthy functioning of communities. Kills are also aesthetically unpleasant because they litter coastal waters with rotten smelly carcasses. The effects of a fish kill may extend further if birds and other predators consume contaminated fish (OzEstuaries).

For further information on animal kills and a detailed explanation of what factors cause kills see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Toxicants Water Quality	<$100	Easy Easy	Moderate Moderate

Links to issues

- Animal disease and kills
- Aquaculture – accidental culture and release of pathogens
- Biota (plants and animals) lost/ disturbed
- Episodic and large scale events (drought, floods, storms, cyclones)
- Eutrophication
- Harmful algal blooms
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflows, dumping of toxicants, wastewater or organic matter
- Poor water quality: high bacteria/ pathogen counts, high toxicant levels, anoxic or hypoxic conditions (i.e. no/ low dissolved oxygen), low/ high pH

Monitoring locations and frequency

Animal kills occur sporadically and as such are monitored when and where they occur.

Data measurement methods

"Investigation and Valuation of Fish Kills" (American Fisheries Association, 1992) supplies information on the procedures and guidelines for investigating kills.

Excerpt from the Qld EPA website

As much as possible of the following information [relating to a kill] should be recorded:

- Name, address, and contact number of the person who initially report the kill in case further information is required by the investigating scientist;
- The exact location of the kill and an estimate of the area affected;
- The date and time of discovery, and an estimate of when the fish-kill might have happened;
- Weather conditions at the time of discovery and for the 24 hours previously;
- An estimate of the number and size of fish affected, and the names or types of fish or other animals such as crabs involved;
- Whether sick or dying fish are also present, and if so, how they are behaving;
- Whether unaffected fish are also present; if only dead specimens are present, their state of decay, and whether some are less decayed than others;
- Whether any unusual or abnormal materials were present such as oil slicks, discoloured water, recently dumped rubbish;
- Whether any samples of dead fish, affected water, or other materials have been taken, and where they are being kept (see below); and,

- Any other factual information which could be relevant, such as industries or agricultural activities in the vicinity of the kill.
- Because of the speed with which dead fish deteriorate and contaminated water flows away, it may help a subsequent investigation if on-the-spot samples are taken.

What to sample:

- Both dead and dying fish (and any other animals affected);
- Sediments (mud or sand) from the water in which dead fish are found;
- Water; and
- Any materials such as oil slicks or other foreign matter in the water.

Clean containers should be used to store the samples. Glass jars or bottles are best, but plastic may be used if glass is not available. Plastic bags are acceptable for dead fish. Large (1-2 litre) soft drink bottles are ideal for storing water samples. Jam jars (150 grams or bigger) are ideal for storing sediment. Anything smaller than these sizes is of limited value for chemical analysis. Bottles and jars should be pre-cleaned with hot water and detergent and rinsed several times in the water being sampled before a sample is taken. If possible, several samples of each kind should be taken, for example at least 3 fish, 3 sediment samples, and 3 bottles of water. If a discharge or drain site is suspected as a source of contamination, samples should be taken both upstream and downstream of this, and clearly labelled with a waterproof pen or similar means. All samples should be preserved by refrigeration, or kept on ice. If the area is remote and/ or collection of samples by an investigator is unlikely for more than 24 hours, samples should be kept in a deep freeze. DO NOT freeze water samples without leaving an airspace of about 20% of the volume to allow for expansion.

Data analysis and interpretation

Excerpt from OzEstuaries:

Globally, over half the fish kills result from natural causes (e.g. life cycle events, infectious diseases, bacteria and protozoa, decreasing water levels, reduced water quality, elevated water temperatures on foreshores, and changes in salinity caused by heavy rain).

Fish kills often occur when dissolved oxygen concentrations drop to lethal levels during the decomposition of organic matter. When oxygen is depleted, anoxic and hypoxic conditions develop and anaerobic organisms take over the degradation of organic matter. Anaerobic respiration gives rise to hydrogen sulfide and ammonia gas that can also be toxic to fish and other organisms (Connell and Miller, 1984).

Degradation of algal biomass derived from algal blooms can cause water column oxygen to be consumed, and often results from excessive nutrient loads (e.g. eutrophication). Some point-sources of nutrients to coastal waterways are wastes from aquaculture operations, sewage discharged from yachts, boats and ships and coastal discharges such as outfalls from industry. The risk imposed by point-sources of nutrients in coastal waterways is higher in areas with large population densities or with a significant tourism, and can be estimated by the number of point-sources per unit area of coastline. Nutrient loads from diffuse sources (e.g. intensive agricultural in catchments and urban stormwater) are often larger and more difficult to control.

Rainfall following the dry season in tropical regions can also mobilise organic-rich detritus (e.g. rotting weeds, grasses, and stormwater rubbish) into coastal waters and these can have a very high biological oxygen demand (Veitch, 1999). Links have also been found between the artificial opening of lagoons and fish kills, because shallow areas can be exposed to air causing the dieback of large amounts of filamentous algae (Wilson *et al.*, 2002).

Inappropriate use of pesticides may also lead to local fish kills. Examples include endosulfan runoff from agricultural areas when this chemical is applied before rainfall (Napier *et al.*, 1998) and drift from chemicals used to control mosquitoes and other biting insects in intertidal wetlands. Birds are also sensitive to the long-term effects of toxicants (e.g. herbicides, pesticides and heavy metals) due to their high metabolic rate. Impacts may be acute and result in death or be chronic, leading to reduced reproductive capacity. The 'Industrial Point Source Hazard' and 'Stormwater Discharges' indicators can be used to assess toxicant risk from urban and industrial sources. The 'Pesticide Hazard' indicator can be used to assess toxicant risk from agricultural sources (OzEstuaries).

Runoff from acid sulfate soils (ASS) can cause fish kills (DEH, 2004). The fish die from the metabolic impacts of low pH itself, or from the toxicity of heavy metals mobilised with the drainage. This may result from natural processes but in many cases, drainage of wetlands (e.g. mangroves and salt marshes) leads to increased oxidation of ASS and potential acid sulfate soils (PSS), with pH levels becoming extremely low. Coastal waterways with rivers in acid hazard zones are most at risk for acid sulfate drainage. Outbreaks of harmful algae (e.g. *Pfiesteria*) produce a variety of biotoxins that kill fish and birds (see http://www.marine.csiro.au/LeafletsFolder/47pfiest/47.html). Birds and fish that feed on filter-feeding molluscs may be particularly susceptible because such organisms concentrate contaminants.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality and/or animal health monitoring.

References and further information

American Fisheries Society. 1992. *Investigation and Valuation of Fish Kills.* American Fisheries Society Special Publication Series 24. 96pp.

Connell, D.W. and Miller, G.J. 1984. *Chemistry and Ecotoxicology of Pollution.* John Wiley & Sons, N.Y.

CSIRO Marine Research. http://www.marine.csiro.au/LeafletsFolder/47pfiest/47.html

Department of Environment and Heritage (DEH), (Commonwealth). 2004. Coasts and Oceans. National Coastal Acid Sulfate Soils. http://www.deh.gov.au/coasts/cass/index.html

Environment Protection Agency (EPA) (Queensland). 1999. *Water Quality Sampling Manual: for use in testing for compliance with the* Environmental Protection Act 1994. 3rd Edition. EPA, Queensland Government, Brisbane. http://www.epa.qld.gov.au/publications?id=330

Napier, G.M., Fairweather, P.G. and Scott, A.C. 1998. Records of fish kills in inland waters of NSW and Queensland in relation to cotton pesticides. *Wetlands* (Australia) 17: 60-71.

National Land and Water Resources Audit. 2002. *Australian Catchment, River and Estuary Assessment 2002*. Volume 1, 192 pp. National Land and Water Resources Audit, Commonwealth of Australia, Canberra.

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia.

Wilson, J., Evans, P. and Kelleher, N. 2002. Fish kills in Cockrone Lagoon - Implications for entrance opening of coastal lakes. *Proceedings of Coast to Coast 2002 - Source to Sea.* Pp. 101-104. Tweed Heads.

Veitch, V. 1999. *The Fish Kill Report.* Sunfish Queensland Inc., Margate, Qld.

Glossary

Anaerobic – In the absence of oxygen.

ASS – Acid sulphate soils

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Biomass – The total weight of all living organisms in a biological community or of a particular species/ group.

DO – dissolved oxygen

EPA – Environment Protection Agency.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

NLWRA – National Land and Water Resources Audit

PSS – Potential acid sulphate soils

Sessile – Plants or animals that are permanently attached to a surface.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.4 Indicator: Animal or plant species abundance

Definition

This indicator documents the abundance of specific animal or plant species.

Rationale

Estuarine, coastal and marine systems contain many species that are important to humans for economic, recreational or cultural reasons. The observed reduction in animal and plant numbers occurring today is a growing global concern. Species abundance is affected by numerous environmental factors and the effects of a change in abundance, (particularly to keystone species), can be dramatic, resulting in significant impacts to ecosystem health and human interests. A reduction in numbers of key animal and plant species from communities within estuarine, coastal, and/ or marine subsystems is a good indicator of human induced changes to environmental conditions. Within most systems there will be an animal or plant species which is susceptible to the slightest change in a particular stressor, and therefore, a good indicator species for changes to that stressor.

Fish abundance and invertebrate abundance were used as one determinant of the fish condition index and sediment quality index, respectively, in the National Estuary Assessment (NLWRA, 2002).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Habitat Sediment Quality Species Composition	>$100	Hard Easy Hard	Hard Moderate Hard

Links to issues

- Animal disease and kills
- Biodiversity decreased
- Biota (plants and animals) lost/ disturbed
- Catchment landuse and run-off
- Climate change/ global warming
- Commercial and recreational fishing, shell collecting, bait collecting (including by-catch, illegal practices)
- Competition by pests (plants or animals)
- Decreased environmental flows (dams, water extraction)
- Dredging and extractive operations (sand and gravel mining)
- Episodic and large scale events (drought, floods, storms, cyclones)
- Eutrophication
- Habitat loss or disturbance (e.g. for buildings, construction, foreshore development, roads and bridges, marine facilities and infrastructure, aquaculture, urbanisation, tourism, trawling, recreational access, etc.)
- Impeded fish/ animal passage (barriers, impoundments and weirs)
- Nuisance growth of aquatic plants or algae (harmful algal blooms)
- Point source pollution
- Poor water quality: high bacteria/ pathogen counts, high toxicant levels, anoxic or hypoxic conditions (i.e. no/ low dissolved oxygen), low/ high pH, high turbidity

Monitoring locations

Monitoring locations will depend on what species is being monitored, which in turn, will depend on aspects of the management actions being monitored. A hypothetical example would be, if the management action is targeting over-harvesting of certain species of coral for the aquarium trade, then the abundance of those coral species on coral reefs will be monitored at sites where those species are currently collected, as well as at control (undisturbed) sites.

Monitoring frequency

Monitoring frequency will depend on what species is being monitored, which in turn, will depend on aspects of the management actions being monitored. Monitoring may occur at monthly (for highly unpredictable and patchy species) through to annual (for more stable species) intervals, or may be dependent on the perceived intensity of a threat.

Data measurement methods

Some animals and plants will respond to a change in a particular stressor more readily than others. For example, if monitoring for the changes to the stressor 'sediment quality' then light dependent or sessile biota should be chosen. When choosing 'species composition' the following criteria should be considered (Saunders *et al.*, 1998):

- Biological/ ecological representative – Habitat specificity; Geographic range; Local population size; and Life span
- Reproductive strategy
- Taxonomic representativeness
- Sensitivity to a particular stressor
- Practicality of sampling and analysis
- Existing knowledge

This indicator would be measured using standard field sampling techniques for measuring species abundance (e.g. line transects, quadrats, catch per unit effort, etc.). The exact protocols used, need to be defined and developed depending on the species to be monitored. Protocol development may need specialised assessment and pilot studies.

Data analysis and interpretation

In general, due to the highly variable nature of species numbers both temporally and spatially, initially there may be no standard data available to compare against. Results from initial abundance studies will form the baseline data against which future results can be compared. Species abundance will change naturally (seasonal variation) or due to human impacts (e.g. pollutants, habitat removal, animal/ plant collection, etc.). Monitoring of control (undisturbed) and impacted sites over multiple years, perhaps decades, will be needed to help determine if the change in abundance is natural or not. A constant difference in abundance between the control and impacted site, or a continual decrease at a site can indicate that human activities are impacting on species numbers. When a decrease in abundance is observed together with a reduction in the average size of animals, then this may indicate that the species is being over-harvested.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting habitat quality and species abundance/ distribution monitoring.

References and further information

Berry, P.F. (Ed.) 1986. Faunal Surveys of The Rowley Shoals, Scott Reef and Seringapatam Reef North-western Australia. Records of the Western Australian Museum, Supplement No. 25, Perth. 106pp.

Berry, P.F. (Ed.) 1993. Marine Faunal Surveys of Ashmore Reef and Cartier Island North-western Australia. Records of the Western Australian Museum, Supplement No. 44, Perth. 91pp.

Berry, P.F. and F.E. Wells (Eds.). 2000. Survey of the marine fauna of the Montebello Islands, Western Australia and Christmas Island, Indian Ocean. Records of the Western Australian Museum. Supplement 59. Western Australian Museum, Perth. 127pp.

Hutchins, J.B. 2003. Checklist of marine fishes of the Dampier Archipelago, Western Australia. In Wells, FE, DI Walker and DS Jones (Eds.). The Marine Flora and Fauna of the Dampier Archipelago, Western Australia. Western Australian Museum, Perth. 453-478.

National Land and Water Resources Audit. 2002. Australian Catchment, River and Estuary Assessment 2002. Volume 1, 192 pp. National Land and Water Resources Audit, Commonwealth of Australia, Canberra.

Newman, S.J., G.C. Young and I.C. Potter. 2004. Characterisation of the Inshore Fish Assemblages of the Pilbara and Kimberley Coasts. FRDC Project No. 2000/132. Department of Fisheries. 204pp.

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Line transect – A straight line placed on the ground along which ecological measurements are taken.

NLWRA – National Land and Water Resources Audit

Quadrats – An ecological sampling unit that consists of a square frame of a known area.

Sessile – Plants or animals that are permanently attached to a surface.

Spatial – Pertaining to space or distance.

Taxa – A taxonomic group of organisms (of any rank, e.g. species, genera, family) considered to be distinct from other such groups.

Temporal – Pertaining to time.

7.5 Indicator: Animals killed or injured by litter (entanglement, starvation, suffocation)

Definition

This indicator documents the number of animals killed or injured by litter.

Rationale

The presence of litter in estuarine, coastal and marine systems can harm animals that eat, become entangled in, or are suffocated by, the litter. Also, toxic substances can leach out of litter, which then bioaccumulates up the food chain. One quite simple example of this is the toxic effect of cigarette butt litter. Toxic substances leach out of cigarette butts and can kill small animals. Animals also mistake butts for food. The toxic chemicals absorbed by cigarettes' cellulose acetate filters and found in butts' remnant tobacco, are quickly leached from the butts by water (Global litter information gateway).

Many species of endangered or threatened marine mammals, turtles and seabirds are particularly at risk from litter. The Global Litter Information Gateway reports that approximately 100,000 marine mammals and turtles, and 700,000 to 1 million seabirds are killed worldwide by litter every year. In Australia it has been reported that 0.8% of New Zealand fur-seals on Kangaroo Island suffer entanglements each year (Page *et al.*, 2003). Over a four year period, 136 Australian fur-seals were observed with plastic neck collars in Tasmanian waters alone (Pemberton *et al.*, 1992). At least 10% of Australian pelicans along the NSW coast were found to be suffering from entanglement by fishing line (NSW Scientific Committee, 2004). Litter thus poses a large threat to many estuarine, coastal and marine species, particularly threatened or endangered ones.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a

person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Litter	<$5	Easy	Easy

Links to issues

- Rubbish dumping (ships/ boats, tourists/ recreational users, upstream)
- Rubbish/ debris from commercial and recreational fishing (e.g. fishing line, nets, bait bags)
- Tangling/ death of animals and plants by litter

Monitoring locations and frequency

The monitoring of this indicator is opportunistic and as such it is not linked with any set monitoring location or frequency. Areas where dead or injured animals are most likely to be found should be monitored (i.e. bays – where there is lots of boating, seabird nesting sites, and beaches – where animals and litter often get washed up).

Data measurement method

All dead or injured animals should be collected and taken to an appropriate facility to determine the cause of death or rehabilitate the animal if possible. A vet or skilled specialist may be needed to confirm if the cause of death was litter related. The number and species of animal killed or injured needs to be recorded along with the type of litter responsible.

Data analysis and interpretation

The presence of litter impacts the health of animals living in an area. Through the monitoring of the number and species of animal killed or injured and type of litter responsible, the major sources of this harmful litter can be determined and efforts then put in place to reduce its presence in the environment.

Worldwide, people have reported entanglement for at least 143 marine species, including almost all of the world's sea turtles. At least 162 marine species, including most sea birds, have been reported to have eaten plastics and other litter. 177 species of marine animals are known to accidentally eat plastics. Plastics have been found in the digestive tracts of 111 different species of seabirds (Global Litter Information Gateway).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

Derraik, J.G.B. 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin* 44: 842–852.

Faris, J. and Hart, K. 1996. *Seas of Debris: A Summary of the Third International Conference on Marine Debris.* Miami, Florida, 8-13 May 1994. 54 pp. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle.

Global Litter Information Gateway. http://marine-litter.gpa.unep.org/facts/effects-wildlife.htm#top

Laist, D.W. 1987. An overview of the biological effects of lost and discarded plastic debris in the marine environment. *Marine Pollution Bulletin 18* (6B): 319-326.

NSW Scientific Committee. 2004. *Entanglement in or ingestion of anthropogenic debris in marine and estuarine environments – key threatening process declaration*. Final determination. NSW National Parks and Wildlife Service. http://www.nationalparks.nsw.gov.au/npws.nsf/Content/marine_debris_ktp_declaration

Page, B., McKenzie, J., McIntosh, R., Bayliss, A., Morissey, A., Calvert, N., Hasse, T., Berris, M., Dowie, D., Shaughnessy, P.D. and Goldsworthy, S.D. 2003. *A summary of Australian sea lion and New Zealand fur seal entanglements in marine debris pre- and post-implementation of Australian Government fishery bycatch policies.* The Australian Marine Sciences Association Annual Conference 2003, Brisbane, Queensland, 9 - 11th July 2003.

Pemberton, D., Brothers, N.P. and Kirkwood, R. 1992. *Entanglement of Australian Fur Seals in manmade debris in Tasmanian waters*. Wildlife Research 19: 151-159.

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.6 Indicator: Benthic microalgae biomass (in intertidal sand/ mudflat communities)

Definition

This indicator documents the benthic microalgae biomass in intertidal sand/ mudflat communities.

Rationale

"Benthic microalgae (BMA) are single-celled microscopic plants (primarily diatoms and dinoflagellates) and cyanobacteria which inhabit the top 0-3 cm of aquatic sediments. Their biomass can be detected and quantified by chlorophyll a analysis (Dennison and Abal, 1999).

BMA are ecologically important in estuarine, coastal and marine systems as they are a source of food for benthic and suspension feeders and they help stabilize sediments. BMA also help regulate nutrients levels in the water column by regulating nutrient exchange rates between the sediment and water.

Increased nutrient loads into estuarine, coastal and marine environments can, under certain conditions, cause increased plant growth. In intertidal and shallow subtidal sand/ mudflat communities, these nutrient loads may result in increased benthic microalgae growth.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Water Quality	<$30	Moderate Moderate	Moderate Moderate

Links to issues

- Decreased environmental flows
- Diffuse nutrient sources: catchment landuse and run-off (rural and urban)
- Entrance modification (decreased flushing, increased residence times)
- Eutrophication
- Nuisance growth of aquatic plants or algae (and loss of amenity)
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients

Monitoring locations and frequency

There can be significant spatial and temporal variation observed in BMA concentrations. Spatial differences are often observed along gradients, whereas, temporal differences are often observed seasonally. This temporal and spatial variation must be accounted for when designing a field monitoring program.

As much of the eutrophication is thought to be the result of terrestrial human activities, and as estuaries link the land to the sea, they are a good monitoring location for land run-off (Ward *et al.*, 1998).

The monitoring of BMA concentration needs to be conducted as regularly and frequently as possible to determine whether a change is natural variation, or induced by some stressor.

Data measurement methods

BMA biomass can be ascertained by determining the levels of chlorophyll a in sediments. Chlorophyll a concentration is usually determined by filtering a known volume of water sample through 0.45 micron mesh filter paper which is then analysed. The amount of chlorophyll a is then determined using a spectrophotometer and the original sample concentration (μg/l) calculated.

Data analysis and interpretation

Low chlorophyll a levels suggest good condition. However, high levels are not necessarily bad as increased phytoplankton growth tends to support larger heterotroph (e.g. fish) populations. It is the long-term persistence of elevated levels that is a problem. Excessive growth often leads to poor water quality, noxious odours, oxygen depletion, human health problems and fish kills. It may also be linked to harmful (toxic) algal blooms.

Currently, there is very little information on BMA communities as they have been poorly studied (Dennison and Abal, 1999). Observed increases in the BMA in individual waterbodies may be related to increased nutrient concentrations, decreased flow/ changed hydrodynamics (increased residence times) and/ or decreased turbidity (increased light penetration) (i.e. the increasing eutrophication status). It is therefore important to try and correlate a change in BMA to nutrients, hydrodynamics and/ or turbidity changes to determine if changes are natural or due to human impacts.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2003. *Simple Estuarine Response Model II*. http://www.per.marine.csiro.au/serm2/index.htm

Dennison, W.C. and Abal, E.G. 1999. *Moreton Bay Study: A Scientific Basis for the Healthy Waterways Campaign*. 246 pp. South East Queensland Regional Water Quality Management Strategy, Brisbane.

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Benthic – On the bottom of a body of water or in the bottom sediments.

Biomass – The total weight of all living organisms in a biological community or of a particular species/ group.

BMA – benthic micoalgae

Cyanobacteria – Photosynthetic bacteria previously called blue-green algae.

Diatom – Microscopic algae with cell walls made of silicon.

Dinoflagellate – Microorganisms with both plant-like and animal-like characteristics, usually classified as protozoans having two lash-like structures (flagella) used for locomotion.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.7 Indicator: Biomass, or number per unit area, of epiphytes (in seagrass or mangrove communities)

Definition

This indicator documents the change in biomass, or number per unit area, of epiphyte plant growth in seagrass and/ or mangrove communities.

Rationale

Increased nutrient loads into estuarine and marine environments can, under certain conditions, cause increased plant growth. In seagrass and mangrove communities these nutrient loads may result in increased epiphyte plant (and periphyton) growth.

Epiphytes obtain all their nutrients from the water column and are not competitive when nutrient concentrations are relatively low. If nutrient levels increase in the water column, epiphytes become more competitive as they capture and use light more efficiently and are fast growing. Increased epiphyte growth can have detrimental effects on the plant it grows on as it decreases the diffusion rate of nutrients and gases, decreases photosynthesis through shading, and may break seagrass leaves off their stems due to the weight of the epiphyte.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Water Quality	<$30	Moderate Moderate	Moderate Moderate

Links to issues

- Decreased environmental flows
- Diffuse nutrient sources: catchment landuse and run-off (rural and urban)
- Entrance modification (decreased flushing, increased residence times)
- Eutrophication
- Loss of seagrass
- Nuisance growth of aquatic plants or algae (and loss of amenity)
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients

Monitoring locations and frequency

Sites chosen for monitoring will depend on particular aspects of the study. In general, the sites will be in a region were it is thought that nutrients are entering the estuarine or marine system (e.g. river mouths, stormwater inputs, etc.). A control site is also needed as large amounts of epiphyte growth are not always associated with human causes. When comparing different locations, it is important that water depth and wave energy is kept constant. Water depth affects light penetration and hence epiphyte growth, while wave energy affects epiphyte attachment (high wave energy tends to remove epiphytes).

The frequency of monitoring will also depend on particular aspects of the study. For example, if examining diffuse nutrient loads from land run-off, then comparison between the wet and dry seasons would be necessary.

Data measurement methods

Information on monitoring methods for epiphytic plant growth can be found in the EPA (1998) publication on seagrass coverage, McMahon *et al.* (1997), and other scientific publications. Two measurement methods can be used to determine epiphyte growth. Artificial substrates can be used to determine epiphyte growth rates, density, biomass and species composition. These can then be compared to other sites and times. Epiphytes can also be collected directly from the host plant: density and biomass can then be determined and changes compared over time.

Data analysis and interpretation

Increased growth of epiphyte plants (and periphyton) is often observed in response to increased nutrient loads entering the estuarine or marine environment. However, decreased flow/ changed hydrodynamics (increased residence times) and/ or decreased turbidity (increased light penetration), (i.e. the increasing eutrophication status) may also result in a change in epiphyte growth. It is therefore important to try and correlate a change in epiphyte growth to nutrients, hydrodynamics and/ or turbidity changes to determine if changes are natural or due to human impacts.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

EPA. 1998. Changes in seagrass coverage and links to water quality off the Adelaide metropolitan coastline. 27 pp. Government of South Australia. DEH (Department for Environment and Heritage, SA). Website: http://www.environment.sa.gov.au/coasts/coastcare/monitoring.pdf

McMahon, K., Young, E., Montgomery, S., Cosgrove, J., Wilshaw, J. and Walker, D.I. 1997. Status of a shallow seagrass system, Geographe Bay, south-western Australia. *Journal of the Royal Society of Western Australia* 80: 255-262.

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Biomass – The total weight of all living organisms in a biological community or of a particular species/ group.

EPA – Environment Protection Agency.

Epiphytes – Plants or animals that attach themselves to the stem or leaves of plants.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Periphyton – Small epiphytic algae.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.8 Indicator: Biomass, or number per unit area, of macroalgae (in rocky shore, rocky reef or coral reef communities)

Definition

This indicator documents the change in biomass, or number per unit area, of macroalgae in rocky shore, rocky reef or coral reef communities.

Rationale

Macroalgae (commonly called seaweed) are multicellular plants that obtain dissolved nutrients from the water column. They grow both intertidally and subtidally usually attached to hard substrates (e.g. rocks and dead coral skeletons). Due to different pigments within the macroalgae they can be divided into three colour types; red (Rhodophyta), green (Chlorophyta) and brown (Phaeophyta). 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 (Ward *et al.*, 1998).

The presence of certain types of macroalgae often indicates nutrient enriched waters as macroalgae thrive in waters that receive nutrient pollution. This strong relationship between macroalgae and water quality has resulted in much research into using them as indicators (OzEstuaries). In rocky reef, rocky shore and coral reef communities, changes in macroalgal density is a useful indicator of changes to the stressor 'nutrients' or 'aquatic sediments'.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Water Quality	>$100	Moderate Moderate	Moderate Moderate

Links to issues

- Decreased environmental flows
- Diffuse nutrient sources: catchment landuse and run-off (rural and urban)
- Entrance modification (decreased flushing, increased residence times)
- Eutrophication
- Loss of corals
- Nuisance growth of aquatic plants or algae (and loss of amenity)
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients

Monitoring locations and frequency

The density of macroalgae present in rocky reef, rocky shore and coral reef communities should be monitored using standard field sampling protocols (i.e. line transect or plot methods); the locations being determined via pilot studies or expert knowledge.

Algal beds may change quickly in response to disturbances (Ward *et al.*, 1998). They should therefore be frequently monitored in areas where stressors (threats/ pressures) are thought to be affecting them.

Data measurement methods

Detailed monitoring methods for determining macroalgal biomass/ density can be found in Ward *et al.* (1998), and other scientific publications. This indicator would be measured using standard field sampling techniques for measuring algal species biomass or unit per area (i.e. density) (e.g. line transects, quadrats, plots, etc.). The exact protocols used need to be defined and developed depending on the sites to be monitored. Protocol development may need specialised assessment and pilot studies.

Data analysis and interpretation

In general, due to the highly variable nature of algal biomass/ density both temporally and spatially, initially there will be no standard data available to compare against. Results from initial studies will form the baseline data against which future results can be compared. Macroalgal biomass/ density will change naturally (e.g. seasonal variation, recovery from past impact) or due to human impacts (e.g. sediments, nutrients). Monitoring of control (undisturbed) and impacted sites over at least a couple years will be needed to help determine if the change in biomass/ density is natural or not. A constant difference in biomass/ density between the control and impacted site, or a continual increase at a site can indicate that human activities are impacting on macroalgal biomass. When an increase in macroalgal biomass is observed, this may indicate that there is an increase in the availability of nutrients in the system.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

(OzEstuaries). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Ward, T., Butler, E. and Hill, B. 1998. *Environmental indicators for national state of the environment reporting – Estuaries and the sea*. Australia: State of the Environment (Environmental Indicator Reports). 81 pp. Department of the Environment; Canberra. Website: http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Biomass – The total weight of all living organisms in a biological community or of a particular species/ group.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Genera – A taxonomic group of organisms, one level higher than species.

Line transect – A straight line placed on the ground along which ecological measurements are taken.

Primary producers – Photosynthetic organisms that produce a 'food source' for the next level up the food chain.

Quadrats – An ecological sampling unit that consists of a square frame of a known area.

Spatial – Pertaining to space or distance.

Taxa – A taxonomic group of organisms (of any rank, e.g. species, genera, family) considered to be distinct from other such groups.

Temporal – Pertaining to time.

7.9 Indicator: Chlorophyll *a*

Definition

This indicator documents the concentration of chlorophyll a in estuarine, coastal and marine open waters (water column) as an indicator of microscopic plant biomass.

Rationale

The concentration of the photosynthetic green pigment chlorophyll a in estuarine, coastal and marine waters is a proven indicator of the abundance and biomass of microscopic plants (phytoplankton) such as unicellular algae. Chlorophyll data are useful over a range of spatial scales from small coastal waters (estuaries, embayments and coastal lagoons) up to shelf seas. 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. Phytoplankton are the direct or indirect source of food for most marine animals.

Chlorophyll a concentration is a commonly used measure of water quality (as a surrogate of nutrient availability); with low levels suggesting good condition. However, high levels are not necessarily bad and it is the long-term persistence of elevated levels that is a problem. As the long-term levels are important, the annual median chlorophyll a concentration is used as an indicator in State of the Environment reporting (Ward *et al.*, 1998). Chlorophyll a was used as one determinant of ecosystem integrity in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002).

The main cause of excessive algae growth appears to be increased nutrient inputs (indicating eutrophication) but it is also affected by declines in the abundance of filter-feeders (e.g. oysters and mussels), reduced aquatic sediments (i.e. increased levels of light penetration), increased water temperature and changes in flushing rates (i.e. hydrodynamics and freshwater flow regimes). For a detailed explanation of what factors influence chlorophyll a concentrations, the significance of these levels and which waterways are susceptible to elevated levels see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Water Quality	<$30	Moderate Moderate	Moderate Moderate

Links to issues

- Decreased environmental flows
- Diffuse nutrient sources: catchment landuse and run-off (rural and urban)
- Entrance modification (decreased flushing, increased residence times)
- Eutrophication
- Nuisance growth of aquatic plants or algae (and loss of amenity)
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients

Monitoring locations and frequency

There can be significant spatial and temporal variation observed in phytoplankton concentrations. Spatial differences are often observed and temporal differences are observed diurnally, as some phytoplankton move up and down through the water column in a day/ night cycle. This temporal and spatial variation must be accounted for when designing a field monitoring program. Remote sensing methods reduce the effects of spatial variation by covering large areas at one time. As much of the eutrophication in estuarine and coastal waters (resulting in high chlorophyll concentrations) is thought to be the result of terrestrial human activities, and as estuaries link the land to the sea, they are a good monitoring location for land run-off (Ward *et al.*, 1998).

The direct monitoring of chlorophyll concentration needs to be conducted as regularly and frequently as possible to determine whether a change is natural variation, or induced by some stressor. The frequency of remote sensing (satellite imagery) measurements will be set by the return interval of the satellite. Remote sensing (aerial scanners) can obtain data regularly but also at times of interest. A disadvantage with both remote methods is that weather conditions (cloud cover, storms) can prevent regular measurements. Automated, in-situ field equipment (fluorescence) is advantageous in that it can monitor at a high frequency.

Data measurement methods

Detailed monitoring methods for chlorophyll can be found in numerous publications including: the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), guidelines for State of the Environment reporting (Ward *et al.*, 1998), and other scientific publications. Chlorophyll a concentrations (expressed as micrograms per litre - µg/l) can be determined through direct (water samples) and indirect (fluorescence, remote sensing) measurement methods. Chlorophyll a concentration is usually determined by filtering a known volume of water sample through 0.45 micron mesh filter paper which is then analysed. The amount of chlorophyll a is then determined using a spectrophotometer and the original sample concentration (µg/l) calculated. Chlorophyll can also be measured from within the water column using fluorescence with special equipment or via remote sensing. Remote sensing uses colour scanners from either plane or satellite and can be relatively cost effective. However, different water bodies need specific algorithms that must be ground-truthed. Also, values of chlorophyll measurements using remote sensing of waterways which are highly turbid (e.g. tide dominated estuaries) will be affected by the suspended sediment. Despite these limitations, remote sensing measures minimise the effects of temporal and spatial variation.

Data analysis and interpretation

Low chlorophyll a levels suggest good condition. However, high levels are not necessarily bad as increased phytoplankton growth tends to support larger heterotroph (e.g. fish) populations. It is the long-term persistence of elevated levels that is a problem. Excessive growth often leads to poor water quality, noxious odours, oxygen depletion, human health problems and fish kills. It may also be linked to harmful (toxic) algal blooms. High chlorophyll concentrations need to be distinguished from the natural variation observed seasonally, with latitude, and those associated with hydrodynamic features (e.g. upwelling). However, currently there is very little information to make this distinction (Ward *et al.*, 1998). Observed increases in the concentrations of chlorophyll in individual waterbodies may be related to increased nutrient concentrations, decreased flow/ changed hydrodynamics (increased residence times) and/ or decreased turbidity (increased light penetration) (i.e. the increasing eutrophication status). It is therefore important to try and correlate a change in chlorophyll concentration to nutrients, hydrodynamics and/ or turbidity changes to determine if changes are natural or due to human impacts. Default trigger values for chlorophyll a concentrations have been listed in the Water Quality Guidelines for coastal waterways in different geographic regions (ANZECC/ ARMCANZ, 2000a).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. http://www.deh.gov.au/water/quality/nwqms/volume1.html

ANZECC/ ARMCANZ, 2000b. *Australian Guidelines for Water Quality Monitoring and Reporting.* http://www.deh.gov.au/water/quality/nwqms/monitoring.html

CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2003. *Simple Estuarine Response Model II*. http://www.per.marine.csiro.au/serm2/index.htm

Environment Protection Agency (EPA) (Queensland). 1999. *Water Quality Sampling Manual: for use in testing for compliance with the* Environmental Protection Act 1994. 3rd Edition. EPA, Queensland Government, Brisbane. http://www.epa.qld.gov.au/publications?id=330

NLWRA (National Land and Water Resources Audit). 2002. *Australian Catchment, River and Estuary Assessment 2002*. Volume 1, 192 pp. National Land and Water Resources Audit, Commonwealth of Australia, Canberra.

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Ward, T., Butler, E. and Hill, B. 1998. *Environmental indicators for national state of the environment reporting – Estuaries and the sea.* Australia: State of the Environment (Environmental Indicator Reports). 81 pp. Department of the Environment; Canberra. Website: http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

Biomass – The total weight of all living organisms in a biological community or of a particular species/ group.

Embayment – A large indentation of a shoreline, bigger than a cove but smaller than a gulf.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Ground-truthed – To confirm remotely obtained data by physically visiting a site.

In-situ – Latin term for 'in the original place'.

Primary production – Production of a 'food source' by photosynthetic organisms at the bottom of the food chain.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.10 Indicator: Coral bleaching

Definition

This indicator documents the occurrence of coral bleaching.

Rationale

Bleaching is the result of the release/ removal of symbiotic unicellular algae (zooxanthellae) from the coral's tissues. Normally, these zooxanthellae supply the coral with food and give them their normal colour. Coral bleaching occurs in reef corals that are under stress and results in the loss of colour, leaving the coral white. There are several environmental factors that are thought to cause bleaching. These include: disease, increased ultraviolet radiation, storms and heavy rains, excess shade, sedimentation, nutrient and toxicant pollution, salinity changes and increased temperatures. If the stressful conditions occur over a long time the corals will bleach and die. However, if the stressful conditions stop and the system returns to normal, then the bleached corals may recover their zooxanthellae and survive. Mass bleaching events reported on the Great Barrier Reef (GBR) and elsewhere around the world over the last 5-10 years have been triggered primarily by anomalously high water temperatures. The mass bleaching event that occurred in the summer of 2002 affected between 60% and 95% of reefs in the GBR Marine Park. While most reefs that were surveyed survived with relatively low levels of coral death, some locations suffered severe damage with up to 90% of corals killed. Up to 5% of reefs on the GBR have been severely damaged during each of the last two major bleaching events, including the inshore reefs around Bowen and Mackay, and some reefs in the Coral Sea. Full recovery of these badly damaged reefs will take many years to decades. Detailed information about coral bleaching can be found at the GBRMPA (http://www.gbrmpa.gov.au) and AIMS (http://www.aims.gov.au) websites.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Water Quality	<$100	Moderate Easy	Very hard Moderate

Links to issues

- Climate change/ global warming (increased air temperature)
- Coral bleaching
- Poor water quality: elevated water temperature, high nutrients, high turbidity, high toxicants
- Sea surface water temperature (average temperature – changed)

Monitoring locations and frequency

Monitoring locations will be coral reefs within the region. The severity of bleaching can vary substantially according to water depth, location and species of corals, so these factor must be taken into consideration when choosing sites. The monitoring of this indicator is somewhat opportunistic as the general public may be the source of initial reports on bleaching events. These reports of coral bleaching should be confirmed and the location monitored. Monitoring will generally occur during the hotter summer months and in response to reported bleaching events.

Data measurement methods

Information of the monitoring of coral bleaching can be found at the GBRMPA website, AIMS websites, and in scientific publications. This indicator would be measured using standard field sampling techniques for measuring species density/ percentage cover (e.g. line/ video transects, quadrats, etc.). The exact protocols used, need to be defined and developed depending on the area to be monitored. Protocol development may need specialised assessment and pilot studies.

Data analysis and interpretation

Coral bleaching is a natural event. However, the rate at which it is occurring today is unnatural. In general, due to the highly variable nature of coral bleaching events both temporally and spatially, initially there will be no standard data available to compare against. Results from initial studies will form the baseline data against which future results can be compared. A constant difference in coral bleaching events and extent/ severity between the control and impacted sites, or a continual increase in coral bleaching at a site can indicate that human activities are impacting on corals. The stressor most commonly associated with bleaching events is increased sea temperature, but additional stressors such as aquatic sediments, toxicants and nutrients are known to intensify coral bleaching events. Corals generally live in a narrow 'average' temperature range of between 25°C and 29°C. It is the prolonged rise in 'average' monthly summer sea temperature, of as little as 1 or 2°C, and not rapidly changing temperatures that cause bleaching in many coral species.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

AIMS. 2004. *Coral bleaching index.* Website: http://www.aims.gov.au/pages/search/search-coralbleaching.html

GBRMPA. *Coral Bleaching and Mass Bleaching Events.* Website: http://www.gbrmpa.gov.au/corp_site/info_services/science/bleaching/index.html

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

GBRMPA – Great Barrier Reef Marine Park Authority.

Quadrats – An ecological sampling unit that consists of a square frame of a known area.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

Zooxanthellae – Microscopic algae that live in a symbiotic relationship with certain corals, clams, and some sponges.

7.11 Indicator: Death of marine mammals, reptiles, and endangered sharks, caused by boat strike, shark nets, or drum lines

Definition

This indicator documents the number of deaths of marine mammals, reptiles, and endangered sharks caused by boat strike, shark nets or drum lines.

Rationale

Many species of endangered or threatened marine mammals, reptiles, and sharks are particularly at risk from boat strike, shark nets, or drum lines. Shark nets and drum lines theoretically offer some protection to swimmers by ‘fishing’ for potentially dangerous sharks and reducing their numbers around protected beaches, although the need for such protection is debatable. Such anti-shark measures also indiscriminately capture other marine life, including harmless sharks, rays, dolphins, dugong, whales, turtles, etc., some of which are critically endangered. Boat strike is another human related cause of death for marine mammals and reptiles. These animals are air breathers and must surface regularly, therefore, putting them at risk of boat strike. The loss of even a couple of critically endangered animals a year due to humans will have a high impact on the chances of survival of the species. Boat strike, shark nets, and drum lines thus pose a large threat to many marine mammal, turtle, and shark species, particularly the threatened or endangered ones.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. ‘Easy’ complexity would mean that a

person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Species Composition	>$100	Moderate	Moderate

Links to issues

- Biota (plants and animals) lost/ disturbed
- Boating and shipping
- Loss of threatened/ endangered and culturally significant species
- Recreational use (powerboat and jet ski usage)
- Use of anti-shark nets and drum lines

Monitoring locations and frequency

The monitoring of this indicator in relation to boat strike is opportunistic and, as such, it is not linked with any set monitoring location or frequency. Areas where animals are most likely to be hit by boats (i.e. estuaries and bays, marinas and ports, etc.), or where dead animals are likely to be found (beaches – where animals often get washed up), should be monitored. Drum lines or shark nets within the region should be regularly monitored.

Data measurement methods

The species and number of all dead or entangled (but released alive) animals should be recorded.

Data analysis and interpretation

The presence of boats, shark nets and drum lines impacts the health of animals living in an area. The full extent of this impact needs to be fully analysed.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

Environment Protection Agency (Queensland). 2004. *Marine strandings*. Website: http://www.epa.qld.gov.au/nature_conservation/wildlife/caring_for_wildlife/marine_strandings/

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

Drum line – method of fishing utliising a large hook, which may or may not be baited, attached by a heavy chain to a large floating drum, or buoy, which is anchored to the sea floor.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.12 Indicator: Dissolved Oxygen (DO)

Definition

This indicator reports on the amount of dissolved oxygen (DO) present in estuarine, coastal and marine waters.

Rationale

With the exception of air-breathing marine animals like marine reptiles and mammals, all other marine animals use oxygen dissolved in the water to respire. Dissolved oxygen (DO) concentrations are a result of the interaction between oxygen production (i.e. photosynthesis) and oxygen consumption (i.e. aerobic respiration, nitrification, and chemical oxidation) within the water environment and the exchange of oxygen with the atmosphere. Natural processes (e.g. weather, tides, and currents) and human pollution (particularly organic matter) can result in severe reductions in DO levels. Both anoxia (no oxygen) and hypoxia (very low oxygen) are harmful to most marine animals. Anoxia and hypoxia can cause animal kills, a decrease in the available habitat and limit animal movements. Low DO can also result in reducing conditions occurring within the sediments which may cause previously bound nutrients and toxicants to be released into the water column. Anoxic and hypoxic events, and DO, were used as one determinant of ecosystem integrity and water quality, respectively, in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002). For a detailed explanation of what factors influence DO concentrations and the significance of DO levels, as well as related information on anoxic and hypoxic events, see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Water Quality	<$30 >$1000 (capital)	Moderate	Moderate

Links to issues

- Algal blooms and nuisance growth of aquatic plants
- Animal kills
- Anoxic and hypoxic events (i.e. no/ low dissolved oxygen) due to increased oxygen demand
- Diffuse organic matter sources: catchment run-off (rural and urban)
- Episodic and large scale events (drought, floods, storms, cyclones, bushfires)
- Eutrophication
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflows, dumping of organic matter

Monitoring locations and frequency

The location of monitoring sites should be determined on the basis of particular aspects of the study. As bottom waters are more likely to have low DO they should therefore be sampled (building a profile through different depths is often useful). DO should be measured frequently and regularly (continuously if possible). At the very least, two measurement should be taken: during peak oxygen production (midday-early afternoon) and maximum respiration (just pre-dawn) to approximate the diurnal range. Although single DO measurements may be useful for checking for possible low DO causes of animal kills, they are generally not very useful as the diurnal range of DO is required for proper data interpretation.

Data measurement methods

Detailed monitoring methods for DO can be found in numerous publications including: the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), and other scientific publications. DO levels can be measured using two standard methods (membrane electrodes and the Winkler (iodometric) method). For continuous, in-situ measurements, membrane electrodes are the most practical. Both salinity and water temperature affect the solubility of oxygen. Therefore, DO is often expressed as percentage saturation as this is independent of salinity and water temperature. Most of the equipment used to measure DO is able to convert DO mg/l to % saturation.

Data analysis and interpretation

Dissolved oxygen refers to the amount of oxygen contained in water. The solubility of oxygen in water is limited and DO levels usually ranges from 6 to 14 mg/l. Water bodies are determined to be anoxic at oxygen concentrations of near 0 mg/l and hypoxic at oxygen concentrations of less than 2 mg/l. Default trigger values for DO have been listed in the Water Quality Guidelines for different coastal waterways in different regions (ANZECC/ ARMCANZ, 2000a). The effect of nutrient load and environmental conditions on DO in different types of waterways can be examined using the Simple Estuarine Response Model II (SERM II). DO levels change in response to a variety of factors including: salinity, water temperature, atmospheric and hydrostatic pressure, and oxygen consumption and production rates (and therefore factors influencing production and consumption). DO is subject to diurnal (daily) and seasonal variation. It varies over a 24 hour period due to net oxygen production (by plants and algae – photosynthesis) during the day, net respiration at night, and because of the tidal cycle causing mixing of the waters. Therefore, large diurnal variation in DO is more likely to be observed in highly productive systems. Observed decreases in DO of individual waterbodies are primarily related to an increased organic matter load (e.g. from sewage treatment plants and industry, organic runoff or algal blooms), which leads to increased bacterial activity (decomposition by aerobic microorganisms). This increase in activity (increased oxygen consumption) can deplete available oxygen. Low oxygen levels generally affect bottom waters first and most severely. The hydrodynamics of the system can affect DO levels. Stratification (non-mixing) of waters isolates the bottom waters from the oxygen enriching processes (i.e. photosynthesis, exchange with the atmosphere) occurring in the surface waters. Wave-dominated coastal systems are more susceptible to stratification and associated low DO because they typically have low tidal mixing. Acid sulfate runoff may also affect DO, as the oxidation of iron-sulfides can rapidly remove oxygen from the water.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. http://www.deh.gov.au/water/quality/nwqms/volume1.html

ANZECC/ ARMCANZ, 2000b. *Australian Guidelines for Water Quality Monitoring and Reporting*. http://www.deh.gov.au/water/quality/nwqms/monitoring.html

CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2003. *Simple Estuarine Response Model II*. http://www.per.marine.csiro.au/serm2/index.htm

Environment Protection Agency (EPA) (Queensland). 1999. *Water Quality Sampling Manual: for use in testing for compliance with the* Environmental Protection Act 1994. 3rd Edition. EPA, Queensland Government, Brisbane. http://www.epa.qld.gov.au/publications?id=330

NLWRA (National Land and Water Resources Audit). 2002. *Australian Catchment, River and Estuary Assessment 2002*. Volume 1, 192 pp. National Land and Water Resources Audit, Commonwealth of Australia, Canberra.

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Glossary

Aerobic – In the presence of oxygen.

Anoxic – oxygen absent, or too low to support life

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Hypoxic – low levels of oxygen, sub-optimal for supporting life

In-situ – Latin term for 'in the original place'.

Microorganism – Microscopic animal or plant.

Spatial – Pertaining to space or distance.

Stratification – The layering of water due to differences in density.

Temporal – Pertaining to time.

7.13 Indicator: Estuary mouth opening/ closing

Definition

This indicator documents the frequency of estuary mouth opening and closing.

Rationale

When the estuary mouth is open, water exchanges freely between the estuary and sea with the tidal cycle. Many estuaries along the coastline Australia, particularly coastal lagoons, naturally close at times of small freshwater input due to the resulting formation of a sandbar across the mouth. The closure of the estuary causes a 'ponding' of water behind the sandbar and results in reduced/ no flushing of the system. This 'closure' becomes particularly important when nutrient inputs are increased above natural levels. The lack of exchange with the sea means that nutrient levels continue to increase within the closed system, often resulting in eutrophication. The closure of an estuary mouth also affects the movement of animals to and from the sea. This is particularly important for species that migrate to and from estuaries as part of their life cycle. Many estuaries naturally open and close to the sea as a result of natural processes like droughts or seasonal low rainfall. However, estuarine mouth conditions are often altered through human action such as impoundments or water extraction. This unnatural closure of the estuary, particularly over long time periods, is often detrimental to estuarine animals and plants (Vivier and Cyrus, 2002).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics	<$5	Easy	Hard

Links to issues

- Artificial opening or closing of estuary mouth
- Climate change (changed rainfall patterns)
- Entrance modification (dredging)
- Environmental flows – water flows and frequency of floods from catchment water changed from natural by dams, barriers, water extraction, levees, impoundments and weirs, increased hard surfaces, land cover, decreased water velocity
- Episodic and large scale events (drought, floods, storms, cyclones)
- Eutrophication – nuisance growth of aquatic plants or algae
- Impeded fish/ animal passage
- Poor water quality: anoxia, hypoxia, turbidity, high nutrients
- Stratification of waters (change in mixing rates)

Monitoring locations and frequency

Estuary mouths which periodically close will be monitored regularly (at the frequency of closure, e.g. during periods of low freshwater flow).

Data measurement methods

Visits to the estuary mouth at similar tidal states (e.g. lowest water spring tides) will report visually and/ or photographically on whether the estuary is opened or closed to the sea. Tide gauges in estuaries can also be used to monitor mouth opening and closing as a loss of tidal signal indicates that the mouth is closed.

Data analysis and interpretation

Many estuaries open and close to the sea as a result of natural processes. A change from natural in the frequency of estuary mouth opening and closing is an indication of human-induced change.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

Vivier, L. and Cyrus, D.P. 2002. Ichthyofauna of the sub-tropical Nhlabane Estuary, KwaZulu-Natal: drought-related changes in the fish community during extended mouth closure. *Marine and Freshwater Research* 53: 457–464.

Young, G.C. and Potter, I.C. 2002. Influence of exceptionally high salinities, marked variations in freshwater discharge and opening of estuary mouth on the characteristics of the ichthyofauna of a normally-closed estuary. *Estuarine, Coastal and Shelf Science* 55: 223–246.

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Bathymetry – Measuring water depths to determine the topography of the sea floor.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Ichthyofauna – Fish fauna.

Impoundment – An accumulation of water into ponds/ dams by human-engineered blocking of natural drainage.

Spatial – Pertaining to space or distance.

Stratification – The layering of water due to differences in density.

Temporal – Pertaining to time.

7.14 Indicator: Extent/ distribution of key habitat types

Definition

This indicator documents the extent/ distribution of key habitats in estuarine, coastal and marine ecosystems. The following is a list of key habitat types that were identified to be used as habitat extent indicators in the national State of the Environment reporting (Ward *et al.*, 1998):

- Algal bed
- Beach and dune
- Coral reef
- Dune vegetation
- Intertidal reef
- Intertidal sand/ mudflat
- Mangrove
- Saltmarsh

Seagrass

However, the National State of the Environment (SoE) Program is presently reviewing the usefulness of all SoE indicators, including these habitat extent indicators and users should refer to the latest documentation for the recommendations on indicators. Some of these habitat types are also recommended for monitoring for the Matter for Targets: “Native vegetation extent and distribution”. Other habitat types may be defined by regional communities as key habitat types and may also be assessed for extent change.

Rationale

Habitat loss and its effects on biodiversity is a growing global concern. Loss of habitat is a major cause of the decline of coastal species. These habitats support key communities within estuarine, coastal, and/ or marine subsystems and have a high biodiversity, tourism, human use and conservation value. The health of coastal waterways depend on the maintenance of a diverse range of coastal habitat types. These habitats provide a variety of benefits including, shelter, food, breeding grounds, nursery areas and migratory corridors for marine life. Many habitats also help to protect/ buffer water quality and resists storm-related erosion. Critical habitat loss was used as one determinant of ecosystem integrity in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Habitat	>$100	Moderate	Moderate

Links to issues

- Beach and foreshore sediment erosion and accumulation
- Biodiversity decreased
- Episodic and large scale events (drought, floods, storms, cyclones, bushfires)
- Habitat removal, loss and disturbance: trawling, tourism, uncontrolled coastal access (especially off-road vehicles), buildings, construction, foreshore development, roads and bridges, marine facilities and infrastructure, aquaculture, urbanisation, dredging and extractive operations (sand and gravel mining), reclamation, etc.
- Human use and clearing
- Plants or animals disturbed/ lost
- Poor water quality: turbidity, nutrients
- Visual amenity decreased

Monitoring locations and frequency

The extent of each habitat type should be monitored for the whole region using remote sensing tools (satellite platforms, aerial photography) with ground-truthing. More information on monitoring design and strategies for different habitats can be found in Ward *et al.* (1998) and OzEstuaries. Where key habitats are in areas with relatively high pressures/ threats, their extent should be assessed annually. In other areas, where pressures are thought to be less, they should be assessed every 3-5 years.

Data measurement methods

Information on protocols for determining a change in habitat extent can be found in the guidelines for State of the Environment reporting (Ward *et al.*, 1998), other scientific publications, and OzEstuaries. In general, mapping changes in the extent/ distribution of habitat is relatively straightforward, and can often be undertaken by community groups. Aerial photography and satellite imagery can be used, although ground-truthing is advised. Certain aspects of some methods used to monitor habitat extent/ distribution will require expert knowledge (e.g. plant identification, satellite imagery, and sonar interpretation). Depending on the habitat type being measured, aerial photography, satellite imagery, sonar, line transect or quadrats, and/ or systematic towed video surveys can be used to estimate the area of habitat. With recent technological improvements, remote sensing has become a cost-effective tool for monitoring and mapping the diversity, distribution and abundance of habitat, at a range of spatial and temporal scales. Although there would be a significant increase in the cost of data acquisition, hyperspectral data provide many more opportunities than multispectral imagery. Hyperspectral data have been used to successfully map rock platform vegetation, seagrass species, mangroves, saltflats and water quality parameters such as total suspended sediment, chlorophyll, and coloured dissolved organic matter concentrations (Dekker *et al.*, 2001; Brando and Dekker, 2003). Remote sensing technology is of limited value in tide-dominated coastal systems (e.g. deltas,estuaries, and tidal creeks) because of poor water transparency. The area of cover should be mapped to within 10m of true position. This is readily achievable with modern equipment.

Data analysis and interpretation

The causes of habitat expansion or contraction should be defined as habitats are subject to natural forces including storm damage and changes in rainfall and sea level as well as human-induced impacts. It is therefore essential to try and determine what change in habitat extent is natural or not. Information on seagrass, mangrove, saltmarsh, and beach and dune habitat, including what they are and the potential causes of their loss, is given in OzEstuaries. The area of each habitat type, with an estimate of uncertainty (e.g. 95% confidence limits), should be recorded. 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 (Ward *et al.*, 1998).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

Brando, V.E. and Dekker, A.G. 2003. Satellite hyperspectral remote sensing for estimating estuarine and coastal water quality. *IEEE Transactions on Geosciences and Remote Sensing* 41: 1-10.

CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2003. *Simple Estuarine Response Model II*. http://www.per.marine.csiro.au/serm2/index.htm

Dekker, A.G., Brando, V.E., Anstee, J.M., Pinnel, N., Kutser, T., Hoogenboom, H.J., Pasterkamp, R., Peters, S.W.M., Vos, R.J., Olbert, C. and Malthus, T.J. 2001. Imaging spectrometry of water. In: *Imaging Spectrometry: Basic principles and prospective applications*, vol. IV, Remote Sensing and Digital Image Processing. Pp. 307-359. Kluwer Academic Publishers.

NLWRA (National Land and Water Resources Audit). 2002. *Australian Catchment, River and Estuary Assessment 2002*. Volume 1, 192 pp. National Land and Water Resources Audit, Commonwealth of Australia, Canberra.

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Ward, T., Butler, E. and Hill, B. 1998. *Environmental indicators for national state of the environment reporting – Estuaries and the sea.* Australia: State of the Environment (Environmental Indicator Reports). 81 pp. Department of the Environment; Canberra. Website: http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Ground-truthed – To confirm remotely obtained data by physically visiting a site.

Line transect – A straight line placed on the ground along which ecological measurements are taken.

Quadrats – An ecological sampling unit that consists of a square frame of a known area.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.15 Indicator: Extent/ distribution of subtidal macroalgae

Definition

This indicator documents the extent/ distribution of subtidal macroalgal beds in estuarine, coastal and marine ecosystems.

Rationale

Subtidal beds of macroalgae are important elements of shallow waters (<50 m depth) in estuaries, bays and coastal regions (Ward *et al.*, 1998). 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. 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. The presence of certain types of macroalgae often indicates nutrient enriched waters as macroalgae thrive in waters that receive nutrient pollution. This strong relationship between macroalgae and water quality has resulted in much research into using them as indicators (OzEstuaries).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Water Quality	>$100	Moderate	Easy

Links to issues

- Diffuse nutrient sources: catchment landuse and run-off (rural and urban)
- Entrance modification (decreased flushing, increased residence times)
- Decreased environmental flows
- Eutrophication
- Nuisance growth of aquatic plants or algae (and loss of amenity)
- Point sources: industrial discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients

Monitoring locations and frequency

Subtidal algal beds should be monitored using a combination of remote sensing tools and ground-truthing based on diver and video surveys (Ward *et al.*, 1998). 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.

Data measurement methods

Ward *et al.* (1998) provide information on the indicator 'algal bed area', which which should be used as a basis for data measurement methods here. The assemblages and area of cover should be mapped to within 10m of true position and is readily achievable with modern positioning and navigational equipment.

Data analysis and interpretation

Estimates of the area covered by individual assemblage types should be part of the analysis of the survey data. Errors in the mapping and survey process should be estimated (or measured) and tracked throughout an aggregation process across individual patches of assemblages. 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. Information of what causes macroalgae tissue chemistry, extent and species composition to change is provided in OzEstuaries.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Sanderson, J.C. 1997. *Subtidal Macroalgal Assemblages in Temperate Australian Coastal Waters*. Australia: State of the Environment Technical Paper Series (Estuaries and the Sea). 129 pp. Department of the Environment, Canberra. http://www.deh.gov.au/soe/techpapers/series1/pubs/subtidal.pdf

Ward, T., Butler, E. and Hill, B. 1998. *Environmental indicators for national state of the environment reporting – Estuaries and the sea*. Australia: State of the Environment (Environmental Indicator Reports). 81 pp. Department of the Environment; Canberra. Website: http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Genera – A taxonomic group of organisms, one level higher than species.

Ground-truthing – To confirm remotely obtained data by physically visiting a site.

Primary producers – Photosynthetic organisms that produce a 'food source' for the next level up the food chain.

Spatial – Pertaining to space or distance.

Taxa – A taxonomic group of organisms (of any rank, e.g. species, genera, family) considered to be distinct from other such groups.

Temporal – Pertaining to time.

7.16 Indicator: Occurrence of imposex

Definition

This indicator documents the occurrence of imposex within gastropod mollusc populations in estuarine, coastal and marine systems.

Rationale

Imposex is the occurrence of induced male sex characteristics superimposed on normal female gastropods, with the development of male sex organs, the penis and/ or the vas deferens (OzEstuaries). Imposex was first reported in the early 1970s for the common dogwhelk *Nucella lapillus* (Blaber, 1970) and the phenomenon has now been observed and studied in many other species of gastropods worldwide. Imposex has been linked to pollution in marinas, antifouling bottom paints, and tributyltin (TBT), a major component of the antifouling paints (Smith, 1981; Gibbs and Bryan, 1986; Bryan *et al.*, 1987), Furthermore, bioaccumulation of tin within the female has been correlated with an increase in the development of imposex. Gastropods bioaccumulate TBT and its endocrine disruptive effects result in elevated testosterone levels giving rise to imposex (Matthiessen and Gibbs, 1998), ultimately resulting in reproductive failure (Gibbs and Bryan, 1986). Relative penis size index (RPSI) has been proposed as a measure of imposex in gastropods (Gibbs *et al.*, 1987). Measurement of imposex can provide a relatively rapid and inexpensive indication of the status of pollution by TBT in a given ecosystem (Rees *et al.*, 2001). Information on which waterways are most susceptible to imposex is given in OzEstuaries.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a

person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Toxicants	>$100	Very hard	Hard

Links to issues

- Biota (plants and animals) lost/ disturbed – particularly marine gastropod snails
- Boating and infrastructure antifoulants (e.g. TBT)
- Imposex (development of male sex organs in female gastropods)
- Point sources: slipways
- Shipping accidents

Monitoring locations and frequency

The use of TBT on ship hulls has been restricted in most countries (including Australia) to vessels greater than 25 m long and as such the incidence of imposex is greatest in areas of high intensity shipping activity (e.g. around ports). However, TBT may still occur in port and marina sediments which act as a TBT sink left over from its previous use. Therefore, sites close to ports should be monitored for imposex. Remote, control sites should also be chosen. Monitoring should be done every five years or more frequently in highly threatened systems. However, it is important to note that Mensink *et al.* (1996) found juvenile *Buccinum undatum* exposed to TBT soon after hatching developed imposex in a dose dependent manner, whilst adult females exposed to the same conditions showed no signs of imposex. If this applies to other species, and imposex is irreversible in individuals as it is for most species (Foale, 1993), then frequency measures of imposex may be confounded by the life-time of the species concerned. This may not present a problem for species with shorter life spans, but there may be a considerable lag time for longer lived species between lower TBT levels in the environment and correspondingly lower observed incidences of imposex (OzEstuaries).

Data measurement methods

One hundred snails should be collected from each site and sent to a diagnostic laboratory for identification of imposex. It is essential that samples are collected live and either kept alive or correctly preserved to allow accurate analysis. Imposex is determined by penis or vas deferens development in female snails, which is visible through a dissecting microscope.

Data analysis and interpretation

Although antifouling agents are of course highly toxic by design, TBT is probably the most toxic substance that has ever been deliberately introduced to the marine environment and its widespread use has often led to detrimental effects on non-target organisms (OzEstuaries). It can induce imposex, and cause other adverse biological effects even though it may be present at very low concentrations in the water column. The scientific literature detailing the adverse impacts of TBT on the aquatic environment is now quite extensive. Apart from imposex, a wide variety of acute and chronic toxic effects on numerous aquatic organisms have been reported. In addition to direct mortality, sublethal effects include growth and behavioural abnormalities, reduced larval growth, reproductive failure, immune system dysfunction, and nervous system disorders. These effects can be observed across a range of water concentrations of TBT, depending on the sensitivity of the species (Fent, 1996).

In some species, the vas deferens interferes with the oviducts leading to infertility and population decline (Matthiessen and Gibbs, 1998). Nias *et al.* (1993) found imposex in *Lepsiella vinosa* at 14 of the 20 sites sampled, but reported that laboratory experiments showed other factors such as copper and environmental stress may also induce imposex. That imposex in some species may be a less specific indicator of TBT pollution than previously thought has also been noted by Evans *et al.* (1995), who nevertheless concluded that TBT has been the major cause of imposex in *N. lapillus*, and measuring it is still valuable in monitoring the recovery of populations.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

Blaber, S.J.M. 1970. The occurrence of a penis-like outgrowth behind the right tentacle in spent females of *Nucella lapillus*. *Proceedings of the Malacological Society of London* 39: 231-233.

Bryan, G.W., Gibbs, P.E., Burt, G.R. and Hummerstone, L.G. 1987. The effects of tributyltin (TBT) accumulation on adult dog-whelks, *Nucella lapillus*: long-term field and laboratory experiments. *Journal of the Marine Biological Association of the United Kingdom* 67: 525-544.

Evans, S.M., Leksono, T. and McKinnell, P.D. 1995. Tributyltin pollution: a diminishing problem following legislation limiting the use of TBT-based anti-fouling paints. *Marine Pollution Bulletin* 30: 14-21.

Fent, K. 1996. Ecotoxicology of organotin compounds. *Critical Reviews in Toxicology* 26: 1-117.

Foale, S. 1993. An evaluation of the potential of gastropod imposex as a bioindicator of tributyltin pollution in Port Phillip Bay, Victoria. *Marine Pollution Bulletin* 26: 546-552.

Gibbs, P.E. and Bryan, G.W. 1986. Reproductive failure in populations of the dog-whelk, *Nucella lapillus*, caused by imposex induced by tributyltin from antifouling paints. *Journal of the Marine Biological Association of the United Kingdom* 66: 767-777.

Gibbs, P.E., Bryan, G.W., Pascoe, P.L. and Burt, G.R. 1987. The use of the dog-whelk, *Nucella lapillus*, as an indicator of tributyltin (TBT) contamination. *Journal of the Marine Biological Association of the United Kingdom* 67: 507-523.

Gibson, C.P. and Wilson, S.P. 2003. Imposex still evident in eastern Australia 10 years after tributyltin restrictions. *Marine Environmental Research* 55: 101-112.

Matthiessen, P. and Gibbs, P.E. 1998. Critical appraisal of the evidence for tributyltin-mediated endocrine disruption in mollusks. *Environmental Toxicology and Chemistry* 17: 37-43.

Mensink, B.P., Everaarts, J.M., Kralt, H., Ten Hallers-Tjabbes, C.C. and Boon, J.P. 1996. Tributyltin exposure in early life stages induces the development of male sexual characteristics in the common whelk, *Buccinum undatum*. In: Hinton, D.E. (ed.), *Pollution Responses in Marine Organisms 8th International Symposium* (PRIMO 8), 42: 151-154.

Nias, D.J., McKillup, S.C. and Edyvane, K.S. 1993. Imposex in *Lepsiella vinosa* from southern Australia. *Marine Pollution Bulletin* 26: 380-384.

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Rees, C.M., Brady, B.A. and Fabris, G.J. 2001. Incidence of imposex in *Thais orbita* from Port Phillip Bay (Victoria, Australia), following 10 years of regulation on use of TBT. *Marine Pollution Bulletin* 42: 873-878.

Reitsema, T.J. and Spickett, J.T. 1999. Imposex in *Morula granulata* as bioindicator of tributyltin (TBT) contamination in the Dampier Archipelago, Western Australia. *Marine Pollution Bulletin* 39: 280-284.

Reitsema, T.J., Field, S. and Spickett, J.T. 2003. Surveying imposex in the coastal waters of Perth, Western Australia, to monitor trends in TBT contamination. *Australasian Journal of Ecotoxicology* 9: 87-92.

Smith, B.S. 1981. Tributyltin compounds induce male characteristics on female mud snails *Nassarius obsoletus = Ilyanassa obsoleta. Journal of Applied Toxicology* 1: 141-144.

Wilson, S.P., Ahsanullah, M. and Thompson, G.B. 1993. Imposex in neogastropods: an indicator of tributyltin contamination in eastern Australia. *Marine Pollution Bulletin* 26: 44-48.

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Bioaccumulation – the process by which chemical are accumulated in biota with levels increasing up the food chain (i.e. small animals and plants take up toxicants from the waters, and when they are eaten by other animals, the toxicants move up the food chain with higher concentrations being found in higher predators).

Bioindicator – An organism and/ or biological process whose change in numbers, structure, or function points to changes in the integrity or quality of the environment.

Imposex – Development of male sex organs in females.

Spatial – Pertaining to space or distance.

TBT – Tributyltin. A toxic chemical used to prevent the fouling of ship hulls.

Temporal – Pertaining to time.

7.17 Indicator: Pest species (number, density, distribution)

Definition

This indicator is a measure of the number and identity of introduced species documented to be pests at a location.

Rationale

Pests are animal or plant species that have been introduced to a new location, outside their natural range, by human dispersal. A native species which has dramatically increased in numbers to the detriment of other species may also be classed as a pest. Pests may pose the most important long term threat to coastal ecosystems (Cappo *et al.*, 1995). Pests have a wide range of destructive impacts on native biodiversity, harvested resources and cultured species, and potentially on humans because of a reduction in recreational amenity. For these reasons, marine pests are an important indicator for State of the Environment reporting (Ward *et al.*, 1998), and were used as one determinant of ecosystem integrity in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002). Information on how pests are introduced, waterways susceptible to marine pests, the environmental significance and detecting and reporting of pests can be found at the OzEstuaries website. Information on specific marine pests in Australia can be accessed through the National Introduced Marine Pest Information System.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Links to issues

- Aquaculture escapees
- Aquarium releases (plant or animal)
- Biodiversity decreased
- Biota (plants and animals) lost/ disturbed
- Escape of weeds from gardens, dumping garden refuse/ rubbish, etc.
- Habitat lost/ disturbed
- International and domestic shipping/ boating
- Ports/ harbours/ marinas
- Pest outbreaks
- Transport of pests attached to boat hulls, equipment and other infrastructure, in ballast water, via dredge spoil

Monitoring locations and frequency

In general, high risk (i.e. port, harbour, and marina) areas are suggested as pest monitoring sites. This is because an important factor in the establishment of exotic species is the number of visits by international ships (i.e. import opportunities). Shoreline habitats such as salt marshes, mangroves, and beach and dune (Hilton, 2002) areas can also be invaded by exotic species (Cappo *et al.*, 1995). Sites should be monitored for pests quarterly (i.e. summer, autumn, winter, and spring), as the chances of pest eradication once introduced are poor, especially once they have become established. Many pest species become reproductive relatively quickly and produce large numbers of young. Therefore, early detection is essential for any chance of their successful removal from an area. If monitoring a well established pest, the frequency of monitoring may be longer.

Data measurement methods

CSIRO's Centre for Research on Introduced Marine Pests (CRIMP) is the national research centre for impacts and management of introduced species. The CRIMP website contains information about marine pests, technical reports, information on community projects, publications, and links to other web-based information sources. CRIMP also developed a National Introduced Marine Pest Information System (NIMPIS; Hewitt *et al.*, 2002) which provides managers, students, researchers, and the general public with access to accurate and up to date information on the ecology, biology, and distribution of known and potential introduced marine species, and control options for those considered pests. Tidal ranges, depths and maximum and minimum values for salinity, temperature, and pH where different introduced species occur are also included in NIMPIS. A comprehensive literature review on Australian ports (Harris and O'Brien, 1998) documents the availability of water temperature, bathymetry and layout, surficial sediment, dredging activity, stratigraphy, habitat, water quality, current and wave, and introduced pest data for 66 Australian ports, and can be used in conjunction with NIMPIS to help in risk assessment. Detailed information on how community groups can monitor and detect marine pests has been produced (Sutton and Hewitt, 2004).

Data analysis and interpretation

Determining whether a species is a pest can be difficult. Criteria have been developed (Williams *et al.*, 2002) to help determine if an out-of-the ordinary species is a pest. Over 80 exotic pest species that are currently found in Australian waters are described, illustrated and pictured in NIMPIS (Hewitt *et al.*, 2002). Information on another 35 species, which are thought to pose a significant threat to Australian waters if introduced, is also provided. 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, and 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 location, changes 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 (Ward *et al.*, 1998).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

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Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Bathymetry – Measuring water depths to determine the topography of the sea floor.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

Univariate – Statistical tests for comparing two or more groups with only one variable.

7.18 Indicator: pH

Definition

This indicator documents the pH of estuarine, coastal and marine waters.

Rationale

pH is a measure of acidity or alkalinity of water on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline). Most aquatic organisms and some bacterial processes require that pH be in a specified range. For example, the activity of nitrifying bacteria is optimal over a narrow pH range from 7 to 8.5 (Henriksen and Kemp, 1988). If pH changes to beyond the preferred range of an organism (including microbes), physiological processes may be adversely affected (ANZECC/ ARMCANZ, 2000a). This is especially true for most organisms if the ambient pH drops to below ~7 or rises to above 9. Physical damage to the gills, skin and eyes of can also occur when pH is sub-optimal for fish, and skin damage increases susceptibility to fungal infections such as red spot disease. pH values are driven to more frequent and greater extremes under eutrophic conditions, allowing algal species with tolerance to extreme pH levels to grow and dominate communities, and to potentially form algal blooms (Hinga, 2002). Changes in pH can also have indirect impacts on aquatic organisms. For example, changes in pH can alter the biological availability of metals, and the toxicities of ammonium, aluminium, and cyanide (ANZECC/ ARMCANZ, 2000a). Increases in pH can also cause the electrostatic forces that bind viruses to particles to be overcome, thus facilitating their release to the water column (Miller, 2001). pH is important in calcium carbonate solubility, which may be important for some shell-forming organisms. pH was used as one determinant of water quality in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Water Quality	<$5 <$500 (capital)	Easy	Moderate

Links to issues

- Animal (fish/ macrobenthos) kills
- Animal lesions and disease
- Decay of infrastructure
- Disturbance of actual or potential Acid Sulphate Soils (ASS) - acid sulphate run-off
- Extraction (mining)
- Habitat lost/ disturbed
- Industrial discharge
- Poor water quality: lowered dissolved oxygen, low pH
- Release of metals and other toxicants

Monitoring locations and frequency

Sites threatened by pH change should be monitored. However, the actual location will depend on aspects of the management issues being monitored. For example, if monitoring for pH change resulting from acid sulfate runoff then monitoring will occur in waters adjoining disturbed acid sulfate soils. The frequency of monitoring will depend on what management issues are being monitored. pH can be monitored continuously or during/ after specific events. Generally, pH measurements are most useful when the full diurnal range is known – pH is usually lowest at dawn and highest during the day (OzEstuaries). Therefore, continuous monitoring of pH using moored, continuously recording pH sensors is advisable. However, if this is not possible, then pH should be measured at dawn and midday to allow for diurnal variation. In some studies pH may be measured after a particular event. For example, if monitoring for pH change resulting from acid sulfate runoff, then monitoring will occur after low/ moderate rainfall (runoff) events in waters adjoining disturbed acid sulfate soils.

Data measurement methods

Detailed monitoring methods for pH can be found in the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), and other scientific publications. It is generally good practice to take pH measurements with all physical, chemical, and biological samples. pH of water is best measured *in situ* using a meter equipped with a pH electrode. A high degree of precision can be expected from the method if careful attention is paid to the calibration and to the maintenance of electrodes and buffer solutions. Values are reported in standard pH units and usually to one or two decimal places. Repeated measures of pH should be reported as medians and ranges of measured values (OzEstuaries).

Data analysis and interpretation

The pH of marine waters is close to 8.2, whereas most natural freshwaters have pH values in the range from 6.5 to 8.0. Most waters have some capacity to resist pH change through the effects of the carbonate-buffer system which helps maintain pH at a near constant level (OzEstuaries). However, it is necessary for data interpretation that baseline (reference) data for the site is known as some waters will have naturally low or high pH levels. The pH of coastal waters responds to changes in: (i) dissolved carbon dioxide concentrations; (ii) alkalinity; (iii) hydrogen ion concentrations; and (iv) in a small way to temperature. The magnitude of the change varies with salinity because various ions are involved in acid-base reactions, and because the concentration of salt influences various equilibrium constants (Hinga, 2002).

Changes to pH levels can result from the following:

- changes in salinity;
- seawater mixing with freshwater/ river water;
- photosynthetic consumption of carbon dioxide (especially in algal blooms);
- decomposition of organic matter;
- nitrification and denitrification;
- disturbance of acid sulfate soils and the reclamation of coastal wetlands;
- mine drainage;
- discharge from coal-fired power stations and other industrial operations;
- acid rain;
- humic acid waters; or
- chemical spills or the dumping of chemicals into stormwater drains.

In a diurnal cycle, the lowest pH is expected at dawn because CO_2 produced by decomposition and aerobic respiration would have accumulated since the previous dusk. Conversely highest pH is expected during the daylight hours, because pH rises at the rate at which carbon dioxide is fixed by plants (OzEstuaries). Default trigger values for pH have been listed in the Water Quality Guidelines but the development values for local objectives is recommended (ANZECC/ ARMCANZ, 2000a). As a general rule, pH values in coastal waters that are higher than 9 and lower than 7 should be investigated (OzEstuaries). The ratio of chloride to sulfate (SO_4) may be measured to check if a drop in pH is the result of acid sulfate soil runoff. Potential acid sulfate soils are present throughout most low-lying coastal regions in Australia. Sulfate input into waterways can occur from acid sulfate runoff, acid rain (sulfur dioxide (SO_2) air pollution), organic acids from swamps/ bogs, or mine site acid runoff. In most regions of Australia this indicator (i.e. pH) will respond to acid sulfate runoff. Potential acid sulfate soils refer to soils containing sulfides (particularly, iron sulfide or pyrite). When these soils are exposed to oxygen and water they produce sulfuric acid runoff that may result in higher sulfate concentrations and low pH in groundwater and waterways. The ratio of chloride to SO_4 (by mass) in seawater is generally constant at approximately 7.2 – in seawater the concentration of chloride is approximately 19,400 mg/l and sulfate is approximately 2,700 mg/l. This ratio remains roughly constant when diluted with uncontaminated rainwater/ freshwater. Therefore, estuaries can be expected to have a similar ratio. Increased levels of sulfate relative to chloride combined with low pH indicate the presence of acid sulfate runoff. A chloride to SO_4 ratio of less than four, and certainly less than two, is a strong indication of an extra source of sulfate from sulfide oxidation (i.e. acid sulfate runoff) (Mulvey, 1993).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

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Glossary

Aerobic – In the presence of oxygen.

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Eutrophic – nutrient rich, or excessive, water body

Humic acid – Acidic water derived from humus (decaying organic matter).

pH – standard, universal measure of acidity/ alkalinity

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.19 Indicator: Presence/ extent of litter

Definition

This indicator reports on the presence/ extent of litter occurring in estuarine, coastal and marine systems.

Rationale

The presence of litter in estuarine, coastal and marine systems detracts from the visual amenity of an area and can harm humans (e.g. broken glass, used needles, etc.) or animals (which eat, become entangled in, or are suffocated by, the litter). Toxic substances can leach out of litter which then bioaccumulates up the food chain. One quite simple example of this is the toxic effect of cigarette butt litter. Toxic substances leach out of cigarette butts and can kill small animals. Animals also mistake butts for food. The toxic chemicals absorbed by cigarettes' cellulose acetate filters and found in butts' remnant tobacco, are quickly leached from the butts by water (Global litter information gateway). Floating litter may aid in the movement (introduction) of marine animals and plants, which may become pests. Many species of endangered or threatened marine mammals, turtles, and seabirds are particularly at risk from litter. According to figures provided in the 'Global litter information gateway' approximately 100,000 marine mammals and turtles, and 700,000 to 1 million seabirds are killed worldwide by litter every year.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Litter	<$5 <$100 (capital)	Very Easy	Easy

Links to issues

- Presence of litter
- Rubbish dumping (ships/ boats, tourists/ recreational users, upstream)
- Rubbish/ debris from commercial and recreational fishing (e.g. fishing line, nets, bait bags)
- Tangling/ death of animals and plants by litter
- Visual amenity decreased

Monitoring locations and frequency

The monitoring locations (e.g. beach, river reach, etc.) and frequency will vary with the goals of the monitoring program and the resources available (e.g. time intensive to monitor, volunteers, etc.). However, in most cases, monitoring every three months would be adequate. Seasonal variation in the movement of litter (e.g. wet season (storms) versus dry season) should be considered when developing a monitoring strategy.

Data measurement methods

Detailed monitoring methods for beach litter can be found in Waterwatch Queensland's 'Community Estuarine Monitoring Manual'. All litter should be collected from a predetermined area, then sorted into different categories and weighed. The different categories used will depend on the goals of the monitoring program (i.e. management actions monitored). For example, litter may be divided by origin (e.g. catchment (storm water, recreation, etc.) and marine (shipping, fishing boat, etc.)) or by type (e.g. plastic, foam, netting, metal, biohazard, etc.).

Data analysis and interpretation

The presence of any litter impacts the visual amenity and health of an area. Through the monitoring of the amount and type of litter present, the major sources, quantities and types of litter can be determined. Recent storms, cyclones, strong winds and strong currents are likely to cause increased litter transport and deposition, particularly of floating debris.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

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Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.20 Indicator: Salinity

Definition

This indicator documents the salinity of estuarine, coastal and marine waters.

Rationale

Salinity is a measure of the amount of salt present in water. Salinity is important in coastal waterways for the following reasons (OzEstuaries):

- salinity is a dynamic indicator of the nature of the exchange system. The salinity of the water within the estuary tells us how much fresh water has mixed with sea water. Also, plots that show the relationship between salinity and other soluble substances (e.g. nutrients) can be used to demonstrate the dynamic or conservative nature of those substances in 'mixing plots';
- salinity is an important determinant of the mixing regime because of the density variation associated with salinity variation, salinity stratification tends to inhibit vertical mixing in an estuary;
- it is an important ecological parameter in its own right; and

it is important in some chemical processes.

Most aquatic organisms function optimally within a narrow range of salinity. When salinity changes to above or below this range, an organism may lose the ability to regulate its internal ion concentration - that is osmoregulation becomes so energetically expensive that the organism may succumb to biotic pressures such as predation, competition, disease or parasitism. Consequently, shifting salinity distributions can affect the distributions of macrobenthos (Boesch, 1977) as well as those of rooted vegetation (e.g. seagrasses) and sessile organisms (Alber, 2002). The nature of the longitudinal salinity gradient (and the position of certain isohalines) is an important factor in the successful recruitment of larval and juvenile fish (Odum, 1970; Whitfield, 1994). Salinity is also an important control on the types of pathogenic organisms and invasive species that can occur in a coastal waterway, on the types species that can occur in algal blooms (Chan and Hamilton, 2001; Kirst, 1995), and on the activity of nitrifying and denitrifying bacteria (Rysgaard *et al.*, 1999). As a general rule, widely varying salinity regimes tend to select for a low-abundance and low diversity suite of species, which are adapted to a broad range of ionic concentrations (e.g. euryhaline species). Salinity was used as one determinant of water quality in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics	<$5	Easy	Moderate
Water Quality	>$500 (capital)	Easy	Moderate

Links to issues

- Climate change (changed rainfall patterns, changing ocean currents, sea level rise, southern oscillation)
- Desalinisation wastes
- Environmental flows – water flows and frequency of floods from catchment water changed from natural by dams, barriers, water extraction, levees, impoundments and weirs, increased hard surfaces, land cover
- Episodic and large scale events (drought, floods, storms, cyclones)

- Estuary mouth open/ close frequency (changed)
- Groundwater – excess caused by artificial ponds and lagoons, changed movement of water into or out of coastal waters, movement of hypersaline/ hyposaline water
- Hypersalinity/ hyposalinity
- Large water release from water impoundments in catchment
- Localised freshwater input (large storm water, industrial discharge, etc.)
- Poor water quality: decreased/ elevated salinity or conductivity
- Saltwater intrusion (movement of salt water into lower concentration/ non-saltwater environment)
- Stratification of waters (change in mixing rates)

Monitoring locations and frequency

Sites threatened by salinity change should be monitored. However, the location will depend on aspects of the management actions being monitored. For example, if monitoring for salt as a pollutant, then monitoring will occur near the source of the pollutant (e.g. desalinization plants). If monitoring for changes in salinity due to hydrodynamics, then a variety of sites along the length of a river, as well as at different depths, may need to be examined for salinity stratification (i.e. lack of mixing). The frequency of monitoring will depend on what management actions are being monitored. Salinity can be monitored continuously or during/ after specific events. Generally, salinity measurements are most useful when continuously monitored using moored, continuously recording sensors. In some studies, salinity may be measured after a particular event (e.g. high rainfall, salt dumping, dredging activities, etc.).

Data measurement methods

Detailed monitoring methods for salinity can be found in numerous publications including: the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), and other scientific publications. Water salinity is best measured in situ using a salinity meter. The presence of charged ionic species in solution enables water to conduct an electrical current, and it is common practice to estimate salinity from electrical conductivity (EC) measurements. Conductivity is best measured in the field using an electronic probe that applies a voltage between two electrodes. The international standard temperature for laboratory conductivity measurements is 25°C, and most modern field instrumentation will compensate for measurements made at other temperatures. However, different standard temperatures were used in the past, so the water temperature at which the measurement was taken should always be reported. Up until around the late 1970's the units of EC were microohms per centimetre (µmohms cm^{-2}) after which they were changed to microSiemens cm^{-2} (1µS cm^{-1} = 1 µohms cm^{-1}) (OzEstuaries).

Data analysis and interpretation

Seawater has a global average salinity of 35 kg m^{-3}, or 35 g/L or 35 parts per thousand (ppt) (OzEstuaries). Salinity levels grade from fresh (< 1 ppt) to almost oceanic (> 30 ppt) within an estuary, as freshwater entering from rivers and streams gradually mixes with seawater. The vertical salinity structure and the nature of salinity variation along the estuary (i.e. how rapidly salinity varies in the vertical and horizontal) reflect the salinity regime of coastal waterways. There are three main salinity regimes in coastal waterways: stratified; partially mixed and fully mixed. Stratified coastal waterways are characterised by a distinct increase in salinity with water depth. Stratification occurs when riverine flow is sufficient to produce a plume of low-density freshwater that can flow over higher-density seawater, and where tidal currents and waves are not strong enough to mix the water column. Such conditions can lead to anoxic and hypoxic events because bottom waters can become isolated from dissolved oxygen enriching processes, including gas exchange across the water surface and photosynthesis by plants in shallow water. In partially mixed coastal waterways, tidal currents generate turbulence that promotes vertical mixing. However, the tidal currents are of insufficient strength to fully mix the water column, and salinity varies both vertically and horizontally. Fully mixed conditions occur in coastal waterways in cases where tide, river or wave energy produces enough turbulence to mix the water column. In this case, salinity is uniform through the water column, but varies between the riverine and oceanic ends. Information on the factors which may cause a change to salinity and the chemical processes affected by salinity can be found at the OzEstuaries website. Conceptual models that show the interaction between 'freshwater' and marine water in embayments, and wave-dominated (deltas, estuaries and strandplains) and tide-dominated (deltas, estuaries and tidal creeks) coastal waterways are available in the OzEstuaries website. The influence of oceanic exchange times and fresh water replacement times on salinity in different types of coastal waterways can be explored in the Simple Estuarine Response Models (SERM II).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

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Glossary

AWQC – Australian Water Quality Centre.

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Embayment – A large indentation of a shoreline, bigger than a cove but smaller than a gulf.

Hypersaline – Above normal levels of salinity.

Hyposaline – Below normal levels of salinity.

Impoundment – An accumulation of water into ponds/ dams by human-engineered blocking of natural drainage.

Sessile – Plants or animals that are permanently attached to a surface.

Spatial – Pertaining to space or distance.

Stratification – The layering of water due to differences in density.

Temporal – Pertaining to time.

7.21 Indicator: Seagrass: depth range

Definition

This indicator reports the change in the depth range of seagrass.

Rationale

Seagrass depth range refers to the minimum and maximum depths that seagrass is found. Seagrass is light dependant and its depth range is a function of the amount of sunlight reaching it. Therefore, light attenuation in the water due to turbidity levels (i.e. due to suspended solids, microscopic algae, dissolved organic matter, etc.) directly impacts on the depth at which seagrass can survive. Areas where seagrass meadows have been lost or their depth ranges are unstable correlate closely with degraded water quality, particularly from high turbidity (EHMP, 2004). Seagrass habitats are important because they provide food for many species (including endangered or threatened species such as dugong and green turtles) and habitat/ nursery grounds for fish and invertebrates (including species which are commercially important). Seagrass beds also assist with nutrient cycling and sediment stabilisation.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Sediment Quality	<$30	Moderate	Moderate

Links to issues

- Bottom vegetation lost by smothering or lower light availability
- Diffuse sediment sources: catchment clearing, landuse and run-off (rural and urban)
- Dredging, trawling: resuspension of sediments
- Dumping of dredged material
- Episodic and large scale events (drought, floods, storms, cyclones)
- Erosion and sedimentation (deposition)
- Habitat lost/ disturbed (smothering)
- Poor water quality: turbidity
- Seagrass cover decreased caused by loss of light availability
- Shipping movement through shallow waters
- Soil disturbance in coastal zone due to development
- Urban development causing loss of coastal habitat and increased erosion

Monitoring locations and frequency

Sites chosen for monitoring will depend on the region but must include sites where threats (turbidity) are thought to be high and control sites where threats are thought to be negligible. EHMP (2004) states that sites should be monitored biannually, ideally during the same month each year. Seagrass depth range may also be measured after a particular event (e.g. high rainfall, algal blooms or dredging activities).

Data measurement methods

Detailed monitoring methods for seagrass depth range can be found at the EHMP website and in other scientific publications. Seagrass depth range measures the difference in height between the shallow distributional limit and the deep distributional limit of a species of seagrass at a site. The most abundant seagrass species should be used as an indicator species, although other species of seagrass should be noted along the transect, as well as macroalgae. Geomorphological features such as sandbars, deep holes and evidence of disturbance (bait worming holes, propeller scars) are also to be noted. An autoset level (dumpy level) and graduated staff are used to calculate elevations and distances to measure seagrass depth range. The depth range and general profile of the seagrass bed is determined along a main transect using basic surveying techniques. Ten replicate transects, approximately 10m apart, 5 on either side of the main transect, are surveyed to record the upper and lower distributional limits (i.e. no profile information is recorded). Where possible, all transects at a site are related back to a Permanent Survey Mark (PSM) to give absolute elevations relative to Australian Height Datum (AHD). This allows comparisons of the seagrass depth range of more than one site over time. To ensure that changes in the upper and lower distributional limits can be recorded, each successive survey at a site starts at the same position and elevation (e.g. a stake in the ground, paint on a rock wall, marked tree, etc.). If the horizontal distance between the upper and lower distributional limits is too great and/ or the water depth prevents the autoset level from being set up, the depth range is approximated within 10-20cm by using a combination of measurements. To do this, the water depth at the deepest seagrass limit is measured at the same time as the elevation of the water level on the intertidal zone. The elevation of the upper limit is also recorded and related back to the deepest seagrass limit.

Data analysis and interpretation

The use of seagrass depth range as an indicator of ecosystem health is based on the assumption that the shallow distributional limit of seagrass is determined by the tolerance of the seagrass to desiccation at low tide, and that the lower distributional limit is determined by light availability (EHMP, 2004). The most common factor leading to seagrass loss is an increase in suspended sediments from terrestrial inputs and sediment re-suspension leading to a long-term reduction in light (EHMP, 2004). The effect of a variety of environmental factors on seagrass depth range, in different types of waterways, can be examined using the Simple Estuarine Response Model II (SERM II).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2003. *Simple Estuarine Response Model II*. http://www.per.marine.csiro.au/serm2/index.htm

EHMP (Ecosystem Health Monitoring Program). 2004. *Seagrass depth range*. http://www.coastal.crc.org.au/ehmp/results_seagrasses_depthrange.html

Kirkman, H. 1997. *Seagrasses of Australia*. Australia: State of the Environment Technical Paper Series (Estuaries and the Sea). 36 pp. Department of the Environment, Canberra. http://www.deh.gov.au/soe/techpapers/series1/pubs/seagrass.pdf

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

Cyanobacteria – Photosynthetic bacteria previously called blue-green algae.

EHMP – Ecosystem Health Monitoring Program (Moreton Bay Waterways and Catchments Partnership).

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.22 Indicator: Sedimentation/ erosion rates

Definition

This indicator reports on the sedimentation or erosion rates within an estuarine, coastal or marine system.

Rationale

Sedimentation is the process by which material is deposited from the water column to the bed. Conversely, erosion occurs when material is removed. The sedimentation/ erosion rate encountered in waterways is naturally variable because of the variability in natural processes causing it (e.g. watercurrent/ flow patterns, climate (rainfall, seasonality), geology, slope (or topography), etc.). Human activity, (e.g. dredging, impoundments, hydrodynamic alterations, land clearing, etc.), may also result in changes to sedimentation/ erosion rates. Enhanced sedimentation/ erosion rates can result in important changes to the form and function of waterways (e.g. they may cause: changed shoreline and mudflats area, channel infilling, habitat/ benthic community smothering or removal, increased turbidity levels, and the burial or resuspension of nutrients, trace elements, toxicants and organic matter). The net result of enhanced sedimentation rates are an increase in the maturity of coastal waterways, and a decrease in their overall lifespans. Reductions in the biodiversity, health and integrity of coastal ecosystems may also occur. In order to make better-informed management decisions there is clearly a need to accurately assess the rate and nature of sedimentation within coastal waterways and any changes in other sedimentological parameters over time (OzEstuaries).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Sediment Quality	<$30	Hard Hard	Hard Hard

Links to issues

- Beach/ foreshore erosion and accumulation
- Biota (plants and animals) lost/ disturbed (smothering, filter feeder and grazing animals, physical abrasion of gills and behavioural changes, lower light availability for benthic plants)
- Boating access decreased (shallow banks/ flats)
- Diffuse sediment sources: catchment clearing, landuse and run-off (rural and urban)
- Dredging, trawling: resuspension of sediments, dumping of dredged material
- Environmental flows – water and frequency of floods from catchment water changed from natural by dams, barriers, water extraction, levees, impoundments and weirs, increased hard surfaces, land cover, decreased/ increased water velocity
- Episodic and large scale events (drought, floods, storms, cyclones, bushfires)
- Erosion and sedimentation (deposition)
- Estuary mouth open/ close frequency (changed)
- Habitat lost/ disturbed (smothering, erosion)
- Poor water quality: turbidity
- Urban development causing loss of coastal habitat and increased erosion

Monitoring locations and frequency

In general, the monitoring of this indicator will occur in estuarine and coastal areas where human induced changes to sedimentation/ erosion rates are thought to be having detrimental impacts on the system. Control sites should also be monitored. Annual monitoring would be sufficient for most studies. However, more frequent monitoring may be needed, depending on the study and aspects of the management actions being monitored.

Data measurement methods

Detailed monitoring methods for sedimentation/ erosion rates can be found in numerous scientific publications. Both sedimentation and erosion rates are measured in terms of vertical change in sediment surface (i.e. accumulation or loss) over time. Sedimentation rate may also be measured in terms of sediment mass accumulation (i.e. density per unit area over time). This is more accurate in systems where compaction or change in sediment composition is important. The method commonly used to determine sedimentation/ erosion rates is to install rods in the sea bed to measure depth changes due to sediment accumulation/ loss. Large changes in sedimentation/ erosion rates occurring over longer time periods can be measured from the differences observed in bathymetric maps from different time periods; this methods cannot estimate recent sedimentation rates.

Data analysis and interpretation

Changes in sedimentation/ erosion rate data can be used to determine whether a waterway has been subjected to enhanced sediment loads or erosion caused by human action. A significant increase in sedimentation rate within an area is often the result of increase sediment load entering the system (e.g. from land clearing) or increased resuspension and deposition from within the system (e.g. from dredging activities). Changes to the hydrodynamics of a waterbody will result in changes to sedimentation and/ or erosion rates, (e.g. sea walls can change the water-current pattern occurring along the coast and cause increased beach erosion in some areas and increase sand accumulation in others).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Benthic – On the bottom of a body of water or in the bottom sediments.

Impoundment – An accumulation of water into ponds/ dams by human-engineered blocking of natural drainage.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

Topography – Detailed study of the surface features of a region.

7.23 Indicator: Targeted pathogen counts

Definition

This indicator documents the numbers (counts) of targeted pathogens in estuarine, coastal and marine systems.

Rationale

A pathogen is a bacterium, virus, protozoan, or fungus that causes disease in humans or estuarine/ marine organisms. Pathogens present a hazard to humans recreating in infected waters or beach sands when an infective dose colonizes a suitable growth site in the body and leads to disease. Sites of infection are the alimentary canal, ears, eyes, nasal cavity, skin and upper respiratory tract (WHO, 2001a). Some exposure pathways include head or face immersion, swallowing water (including splashed water during boating), entering water up to or beyond waist level and skin abrasions (WHO, 2001a). Consumption of contaminated shellfish also exposes humans to marine pathogens (OzEstuaries). Faecal streptococci/ enterococci are the recommended indicator for human pathogens in marine waters and gastrointestinal symptoms are a frequent health outcome associated with exposure (WHO, 2001a). Other illnesses and conditions caused by contact with pathogen-contaminated waters include skin rashes, typhoid fever, acute febrile respiratory illness (AFRI) (Fleisher *et al.*, 1996a), salmonellosis, meningo-encephalitis, cryptosporidiosis and giardiasis (Prüss, 1998). An example of a pathogenic disease affecting fish assemblages is epizootic ulcerative syndrome. Low-pH increases the susceptibility of fish to this fungal disease (OzEstuaries). Pathogens and shellfish closures were used as two determinants of ecosystem integrity in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. ‘Easy’ complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. ‘Moderate’ would require a person with a couple years experience, and ‘hard’ would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Toxicants	<$100	Moderate	Moderate

Links to issues

- Animal (fish/ macrobenthos) kills
- Animal behaviour (changed)
- Animal lesions and disease
- Aquaculture - accidental culture and release of pathogens
- Diffuse sources: catchment run-off, storm water and land management practices (animal and human wastes)
- Human health problems (infections, gastro, viruses, disease, etc.)
- Poor water quality: high bacteria/ pathogen counts
- Sewage discharge from vessels
- Sewage treatment plant discharge, sewage overflow events
- Shellfish/ fisheries closures

Monitoring method

It is not possible to routinely measure all viruses, parasites and dangerous bacteria in seawater. Therefore, faecal indicator bacteria are used as indicators (e.g. faecal/ thermotolerant coliforms, E. coli, enterococci/ faecal streptococci). The presence of these organisms in high numbers indicates contamination by faecal material from warm-blooded animals (including humans) (OzEstuaries). For marine waters, only faecal streptococci (or enterococci) show a dose-response relationship for both gastrointestinal illness (Kay *et al.*, 1994) and AFRI (Fleisher *et al.*, 1996b). Faecal streptococci are therefore recommended as the faecal indicator for monitoring marine water quality for recreational use (WHO, 2001a). A new approach recommended by the World Health Organisation (WHO) includes conducting a sanitary assessment of recreational water catchments (including interviews and site visits to determine all contamination sources) and use of the enterococci group as bacterial indicators. This is a two-component approach to assessing risk of illness from recreational bathing. It is expected that Australia will adopt the WHO approach. Guidelines for conducting sanitary assessments in Australia using the WHO approach have been completed by the Water Services Association of Australia (WSAA). The WSAA guidelines will be considered for inclusion into guidelines presently being developed by the National Health and Medical Research Council (NHMRC).

Monitoring locations and frequency

Sites chosen for monitoring will depend on the region and which pathogen/ bacteria is being monitored. In general, sites where pathogen threats are thought to be high (e.g. sewage overflow sites) should be monitored. The movement of viruses through estuarine and coastal waters can be predicted via the use of conceptual models depicting sediment transport in different coastal waterway types which are available at the OzEstuaries website. Prediction of pathogen movement may help with the choice of monitoring location. Monitoring should occur at regular intervals not exceeding one month. During the summer (i.e. the swimming season) and in waterways susceptible to faecal contamination, monitoring should occur more frequently. Event monitoring (i.e. after sewage overflow events) should also occur.

Data measurement methods

Faecal indicator bacterial densities should be assessed according to national guidelines (ANZECC 1992; reproduced in ANZECC/ ARMCANZ 2000a). Detection methods are standardised: AS4276.8 for the estimation of the most probable number or AS 4276.9 for the membrane filtration method (Standards Australia, 1995a,b) (OzEstuaries).

Data analysis and interpretation

Default trigger values for pathogen (microbiological) concentrations have been listed in the Water Quality Guidelines for Australian waterways (ANZECC/ ARMCANZ, 2000a). Some pathogens occur naturally in marine waters. Others are carried into waterways after defecation/ urination/ shedding from human or animal hosts (e.g. via sewage effluent, agriculture and stormwater runoff, sewage from ships, recreational population using the water, industrial processes, wildlife, septic tanks near the shore and urban development) (WHO, 2001a). Rivers discharging into coastal areas may carry abundant micro-organisms from these diverse sources. High concentrations of pathogens usually occur after storms due to surface runoff, sediment re-suspension and because rainwater gets into sewerage pipes through faults and illegal connections and causes sewage to overflow. Contamination from human sources (e.g. faecal pollution) presents a greater risk to humans than contamination from animal sources because many animal pathogens are not infectious to humans. Risks to humans from pathogenic organisms are higher in areas with large population densities or with a significant tourism, and are perhaps best assessed by the volume of stormwater and coastal discharges indicators. Different pathogen-indicator organism relationships may exist between saline and fresh waters, so the same level of faecal indicator bacteria in freshwater and marine environments does non mean the health risk is the same (WHO, 2001b). Information on which waterways are susceptible to pathogens, the environmental consequences of high pathogen levels, and the factors affecting pathogen numbers and survival is given in OzEstuaries.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. http://www.deh.gov.au/water/quality/nwqms/volume1.html

ANZECC/ ARMCANZ, 2000b. *Australian Guidelines for Water Quality Monitoring and Reporting.* http://www.deh.gov.au/water/quality/nwqms/monitoring.html

Fleisher, J.M., Kay, Salmon, R.L., Jones, F., Wyer, M.D. and Godfree, A.F. 1996a. Marine waters contaminated with domestic sewage: nonenteric illnesses associated with bather exposure in the United Kingdom. *American Journal of Public Health* 86:1228-1234.

Fleisher, J.M., Kay, D., Wyer, M. and Merrett, H. 1996b. The enterovirus test in the assessment of recreational water-associated gastroenteritis. *Water Research* 30: 2341-2346.

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Miller, B.M. 2001. Issues for the modelling of fate and transport of viruses in estuarine environments. 15th *Australasian Coastal and Ocean Engineering Conference*. September 2001, Gold Coast. NLWRA (National Land and Water Resources Audit). 2002. *Australian Catchment, River and Estuary Assessment 2002*. Volume 1, 192 pp. National Land and Water Resources Audit, Commonwealth of Australia, Canberra.

(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Prüss, A. 1998. A review of epidemiological studies from exposure to recreational water. *International Journal of Epidemiology* 27: 1-9.

Standards Australia 1995a. *Method 8: Faecal streptococci-Estimation of most probable number (MPN).* AS4276.8.

Standards Australia. 1995b. *Method 9: Faecal streptococci-Membrane filtration method.* AS4276.9.

WHO (World Health Organisation). 2001a. *Guidelines for safe recreational-water environments. Volume 1: coastal and fresh waters*.

WHO (World Health Organisation). 2001b. *Bathing water quality and human health. Outcome of an expert consultation.* Farnham, UK, April 2001.

Glossary

AWQC – Australian Water Quality Centre.

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Cryptosporidiosis – A disease caused by the protozoan *Cryptosporidium*, which is most commonly transmitted to humans by contact with animal faeces.

Enterococci – A group of bacteria found primarily in the intestinal tract of warm blooded animals.

Epizootic ulcerative syndrome – Red spot disease of fish (caused by a fungus).

Giardiasis – Intestinal disease caused by an infestation with a *Giardia protozoan*.

Meningo-encephalitis – Inflammation of the brain and its membranes.

NHMRC – National Health and Medical Research Council.

Salmonellosis – Infection caused by *Salmonella* (bacteria).

Spatial – Pertaining to space or distance.

Streptococci – Spherical gram-positive bacteria.

Temporal – Pertaining to time.

Thermotolerant – Able to survive in a wide range of temperatures.

WSAA – Water Services Association of Australia.

7.24 Indicator: Total nutrients in the sediments

Definition

This indicator documents the concentrations of total nutrients and dissolved nutrients in estuarine, coastal and marine sediments.

Rationale

The nutrients nitrogen (N) and phosphorus (P) are elements, and are essential building blocks for plant and animal growth. Nitrogen is an integral component of organic compounds such as amino acids, proteins, DNA and RNA. Phosphorus is found in nucleic acids and certain fats (phospholipids). Chemical and biological processes transfer nitrogen and phosphorus through the lithosphere, atmosphere, hydrosphere and biosphere. This is called nitrogen and phosphorus cycling. Nitrogen fixing bacteria convert di-nitrogen gas into organic nitrogen species that can enter the hydrological cycle and food webs. Phosphorus is made biologically available through the weathering of rocks (OzEstuaries). 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 is 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 warn of, or identify the potential for, eutrophication and problem algal blooms in marine waterways. Nutrients exist both as organic and inorganic species, and in dissolved and particulate forms. Total nutrients is the total amount of a nutrient present in all its forms (e.g. total nitrogen (TN) is the sum of the nitrogen present in all nitrogen-containing components). Dissolved nutrients occur as dissolved organic and inorganic forms (e.g. total dissolved nitrogen (TDN) is the sum of the dissolved organic nitrogen (DON) (e.g. proteins, amino acids, urea) and dissolved inorganic nitrogen (DIN) (e.g. nitrate and ammonia)). Dissolved nutrients are readily available for plant uptake. Determining the amounts of both total and dissolved nutrients present within the sediments will give an indication of the amount of bioavailable nutrients present. Nutrient concentration within sediments is important as most of the microbial processing of nutrients occurs here (Ward *et al.*, 1998). Sediment loads of total nitrogen and total phosphate were used as two determinants of sediment quality in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002). Information on sediment nutrient loads, concentrations and budgets, nutrient transport, and on what causes nutrient loads and concentrations to change can be found at the OzEstuaries website. See also, the National Eutrophication Management Program website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Water Quality	>$100	Moderate	Moderate

Links to issues

- Decreased environmental flows and entrance modification (decreased flushing, increased residence times)
- Diffuse nutrient sources: catchment landuse and run-off (rural and urban)
- Eutrophication
- Nuisance growth of aquatic plants or algae (harmful algal blooms), and loss of amenity
- Point sources: industrial and aquaculture discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients

Monitoring locations and frequency

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. 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. 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 subsampling approach could involve five sites sampled monthly. Stratified random sampling is normally used to account for sediment heterogeneity (i.e. a location composed of several different habitats is deliberately divided up so that each individual habitat is randomly sampled) (Ward *et al.*, 1998).

Monitoring should be done at least monthly. 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 (Ward *et al.*, 1998).

Data measurement methods

Detailed monitoring methods for nutrients in sediments can be found in several publications including; the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), and other scientific publications. At each site, surface sediment samples would be collected and analysed for the total amount of a nutrient and the amount in its dissolved form. Sediment carbon and nitrogen are best measured by high temperature oxidation methods (e.g. CHN analyser) (Craft *et al.*, 1991), while phosphorus contents are determined by wet chemical oxidation (Nicholls, 1975). Appropriate standard reference materials should be analysed to check recovery. Nutrient mass accumulation rates in sediment (nutrient cm^{-2} $year^{-1}$) are probably more indicative of nutrient loads than sediment nutrient concentrations because the latter are subject to dilution effects caused by the co-deposition of mineral sediment (Radke, 2002). Calculation of nutrient mass accumulation rates requires that sedimentation rates and bulk density be determined in addition to carbon and nutrient concentrations (OzEstuaries).

Data 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 (Ward *et al.*, 1998). 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. Nutrient loads alone cannot dictate whether a waterway will have a nuisance plant problem (ANZECC/ ARMCANZ, 2000a). Nutrient impacts on coastal waterways vary as a function of both the loads and bioavailability of the nutrients, and the extent to which hydrodynamic features (e.g. water volumes, residence times and extent of mixing) and turbidity levels modulate the stimulatory effects of nutrients on plants and algae (ANZECC/ ARMCANZ, 2000a; Harris, 2001). Chlorophyll a is probably a better 'instantaneous' indicator of trophic status than nutrient concentrations. This is because nutrient concentrations are affected by biological uptake, which in turn are influenced by uptake capabilities, interaction with grazers, temperature, turbulence and turbidity levels (Hinga *et al.*, 1995). Concentrations of N (or P) taken from water column samples can also underestimate nutrient availability in a system because large pools of nutrients can be found in sediment. Trigger values for total phosphorous (TP), filterable reactive phosphate (FRP), total nitrogen, total oxidised nitrogen (e.g. $NO_x = NO_3^- + NO_2^-$) and ammonium are provided on a bioregional basis in the ANZECC/ ARMCANZ Water Quality Guidelines (ANZECC/ ARMCANZ, 2000a). Water Quality Targets Online list water quality targets for TN and FRP for each of ecosystem protection, recreation and aquaculture/ human consumption values. Given the strong influence of tidal action on water column stability and turbidity levels (which affect the potential of plants to take up nutrients), it would be advantageous to derive separate sets of default trigger values and water quality targets for tide- and wave-dominated systems. The effect of nutrient load on environmental conditions (including benthic microalgae) of different types of waterways can be examined using the Simple Estuarine Response Model II (SERM II). Information on the significance of excessive nutrient loads can be found at the OzEstuaries website.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. http://www.deh.gov.au/water/quality/nwqms/volume1.html

ANZECC/ ARMCANZ, 2000b. *Australian Guidelines for Water Quality Monitoring and Reporting.* http://www.deh.gov.au/water/quality/nwqms/monitoring.html

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Cosser, P.R. (ed.). 1997. *Nutrients in marine and estuarine environments.* State of the Environment Technical Paper Series (Estuaries and the Sea). 53 pp. Department of the Environment, Canberra. http://www.deh.gov.au/soe/techpapers/series1/pubs/09compen.pdf

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Glossary

AWQC – Australian Water Quality Centre.

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Benthic – On the bottom of a body of water or in the bottom sediments.

DIN – dissolved inorganic nitrogen.

DON – dissolved organic nitrogen.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

FRP – filterable reactive phosphate.

Grazers – Animals which feed (graze) on small organic particles and algae.

Spatial – Pertaining to space or distance.

TDN – total dissolved nitrogen, the sum of the dissolved organic nitrogen.

Temporal – Pertaining to time.

TN – total nitrogen, the sum of the nitrogen present in all nitrogen-containing components.

TP – total phosphorous.

7.25 Indicator: Total nutrients in the water column

Definition

This indicator documents the levels of total nutrients and dissolved nutrients in estuarine, coastal and marine waters.

Rationale

The nutrients nitrogen (N) and phosphorus (P) are elements, and are essential building blocks for plant and animal growth. Nitrogen is an integral component of organic compounds such as amino acids, proteins, DNA and RNA. Phosphorus is found in nucleic acids and certain fats (phospholipids). Chemical and biological processes transfer nitrogen and phosphorus through the lithosphere, atmosphere, hydrosphere and biosphere. This is called nitrogen and phosphorus cycling. Nitrogenfixing bacteria convert di-nitrogen gas into organic nitrogen species that can enter the hydrological cycle and food webs. Phosphorus is made biologically available through the weathering of rocks (OzEstuaries). 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 is 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 warn of, or identify the potential for, eutrophication and problem algal blooms in marine waterways. Nutrients exist both as organic and inorganic species, and in dissolved and particulate forms. Total nutrients is the total amount of nutrient present in all its forms (e.g. total nitrogen (TN) is the sum of the nitrogen present in all nitrogen-containing components). Dissolved nutrients occurs as dissolved organic and inorganic forms (e.g. total dissolved nitrogen (TDN) is the sum of the dissolved organic nitrogen (DON) (e.g. proteins, amino acids, urea) and dissolved inorganic nitrogen (DIN) (e.g. nitrate and ammonia)). Dissolved nutrients are readily available for plant uptake. Determining the amounts of both total and dissolved nutrients present within the water column will give an indication of the amount of bioavailable nutrients present. Nutrient concentrations within the water column is important as it is from here that nutrients are taken up by phytoplankton which may then form blooms if excess nutrients are present. Water nutrients is an important indicator for State of the Environment reporting (Ward *et al.*, 1998), and was used as one determinant of water quality in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002). Information on water column nutrient loads, concentrations and budgets, nutrient transport, and on what causes nutrient loads and concentrations to change can be found at the OzEstuaries website and the National Eutrophication Management Program website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Water Quality	<$100	Moderate	Moderate

Links to issues

- Decreased environmental flows and entrance modification (decreased flushing, increased residence times)

- Diffuse nutrient sources: catchment landuse and run-off (rural and urban)
- Eutrophication
- Nuisance growth of aquatic plants or algae (harmful algal blooms), and loss of amenity
- Point sources: industrial and aquaculture discharge, sewage treatment plant discharge, sewage overflow events, dumping of nutrient rich wastewater
- Poor water quality: increased nutrients

Monitoring locations and frequency

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. 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. Choice of estuaries within regions could be on the basis of catchments characterized by different land uses – urban/ industrial, rural, mining/ forest operations or undisturbed landforms (national parks, 'old-growth' forest or similar). Within each estuary, a subsampling approach could involve five sites sampled monthly (Ward *et al.*, 1998).

Monitoring should be done at least monthly. 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. 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. Short-term nutrient fluctuations — missed with intermittent sampling — would then be observed (OzEstuaries).

Data measurement methods

Detailed monitoring methods for nutrients in the water column can be found in numerous publications including: the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), guidelines for State of the Environment reporting (Ward *et al.*, 1998), and other scientific publications. At each site, water samples would be collected, and analysed for the total amount of a nutrient and the amount in its dissolved form. Total nitrogen and total phosphorus are determined by analysing unfiltered water samples. Dissolved nutrients pass through a 0.45µm filter and are reported as: soluble reactive phosphorus (SRP) or filterable reactive phosphorus (FRP) in the case of phosphorus; and total dissolved nitrogen (TDN) in the case of nitrogen. TDN can be further analysed for nitrate, nitrite, ammonium and organic nitrogen. The term 'reactive' implies that the nutrient readily reacts with the analytical chemical process. The widely accepted analytical techniques for quantifying nutrients and producing comparable data, are a set of wet chemical processes used in combination with spectrophotometry (also termed colorimetry). The techniques involve blending precise amounts of sample and wet chemicals. A reaction occurs with the 'reactive' nutrient and the solution develops a specific colour. The depth of the colour is proportional to the concentration of the nutrient, and is measured with a spectrophotometer. Total nutrients are measured the same way except the nutrients being quantified are initially converted to a reactive form through a chemical digestion process. There are different techniques and instrumentation for quantifying select nutrients, such as ion chromatography, fluorescence, probes and inductively coupled plasma. When comparing data from less conventional techniques one should always confirm what form of the nutrient is being quantified (OzEstuaries).

Data 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 (Ward *et al.*, 1998). 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. Nutrient loads alone cannot dictate whether a waterway will have a nuisance plant problem (ANZECC/ ARMCANZ, 2000a). Nutrient impacts on coastal waterways vary as a function of both the loads and bioavailability of the nutrients, and the extent to which hydrodynamic features (e.g. water volumes, residence times and extent of mixing) and turbidity levels modulate the stimulatory effects of nutrients on plants and algae (ANZECC/ ARMCANZ, 2000a; Harris, 2001). Chlorophyll a is probably a better 'instantaneous' indicator of trophic status than nutrient concentrations. This is because nutrient concentrations are affected by biological uptake, which in turn are influenced by uptake capabilities, interaction with grazers, temperature, turbulence and turbidity levels (Hinga *et al.*, 1995). Concentrations of N (or P) taken from water column samples can also underestimate nutrient availability in a system because large pools of nutrients can be found in sediment (see sediment nutrients). Trigger values for total phosphorous (TP), filterable reactive phosphate (FRP), total nitrogen, total oxidised nitrogen (e.g. $NO_x = NO_3{}^- + NO_2{}^-$) and ammonium are provided on a bioregional basis in the ANZECC/ ARMCANZ Water Quality Guidelines (ANZECC/ ARMCANZ, 2000a). Water Quality Targets Online list water quality targets for DIN and FRP for each of ecosystem protection, recreation and aquaculture/ human consumption values. Given the strong influence of tidal action on water column stability and turbidity levels (which affect the potential of plants to take up nutrients), it would be advantageous to derive separate sets of default trigger values and water quality targets for tide- and wave-dominated systems. The effect of nutrient load on environmental conditions (including chlorophyll a concentrations) of different types of waterways can be examined using the Simple Estuarine Response Model II (SERM II). Information on the significance of excessive nutrient loads can be found at the OzEstuaries website. The Department of the Environment and Heritage (Australian Government) provides water quality targets online for TN, oxides of nitrogen, TP and filterable reactive phosphate.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

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Waterwatch Australia Steering Committee. 2002. *Waterwatch Australia National Technical Manual. Module 4 – physical and chemical parameters.* Environment Australia, Canberra.

Glossary

AWQC – Australian Water Quality Centre.

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

DIN – dissolved inorganic nitrogen.

DON – dissolved organic nitrogen.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

FRP – filterable reactive phosphate.

Grazers – Animals which feed (graze) on small organic particles and algae.

Spatial – Pertaining to space or distance.

TDN – total dissolved nitrogen, the sum of the dissolved organic nitrogen.

Temporal – Pertaining to time.

TN – total nitrogen, the sum of the nitrogen present in all nitrogen-containing components.

TP – total phosphorous.

7.26 Indicator: Toxicants in biota

Definition

This indicator documents the levels of toxicants in the biota of estuarine, coastal and marine waters.

Rationale

Toxicants are chemicals that harm animals or plants. They can be natural (e.g. metals such as zinc and copper) which are essential for life but become toxic at high concentrations) or unnatural (i.e. man-made substances such as pesticides). A list of potential toxicants is provided in the Water Quality Guidelines (ANZECC/ ARMCANZ, 2000a). 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). Another advantage of monitoring toxicants in biota (via bioaccumulation) over water, is that toxicants are often introduced into the system as a result of an isolated event and therefore concentrations in the water may be too low to be measured most of the time. Contaminated biota may be harmful to human health if eaten. Toxicants in biota, is an important indicator for State of the Environment reporting (Ward *et al.*, 1998). For further information on toxicants including a detailed explanation of what toxicants are, the sources of toxicants, environmental significance of toxicants, and coastal habitats susceptible to toxicants see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a

person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Toxicants	>$100	Hard	Moderate

Links to issues

- Animal kills and disease
- Biota (plants and animals) and habitat lost/ disturbed
- Boating and infrastructure antifoulants (e.g. TBT), slipways
- Human health problems (eating contaminated seafood)
- Imposex (development of male sex organs in female gastropods)
- Point sources: industrial discharge, dumping of toxicants
- Poor water quality: toxicant levels
- Shellfish/ fisheries closures
- Toxicant release: spills, oil spills, insect control chemicals, pesticides/ herbicides, outboard motor emissions, etc.

Monitoring locations and frequency

The indicator would be monitored annually (or as otherwise specified in the SOP (Standard Operating Procedure)) in a small number of carefully selected refuge/ reference areas (possibly nature reserves/ marine parks) and other randomly and explicitly selected sites. Development of the detailed techniques for an SOP will need a specialised assessment and pilot study for each site 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 Jervis Bay Baseline Studies; CSIRO 1994) (Ward *et al.*, 1998).

Data measurement methods

Detailed monitoring methods for toxicants in biota can be found in the guidelines for State of the Environment reporting (Ward *et al.*, 1998), and other scientific publications. 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 (Ward *et al.*, 1998). The species collected for analysis should be a widespread and common species whose populations will not be affected by collection. The species used will also depend on the toxicant being tested for. 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). The Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ ARMCANZ, 2000b) give formal guidance for appropriate analytical methods for water and sediment toxicants. Although there is no guidance for the toxicants in biota, chemicals which have the potential to bioaccumulate are identified.

Data 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, for both synthetic and natural materials the precise level at which an effect can be expressed in the flora [plants] and fauna [animals] 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 (Ward *et al.*, 1998). Chronic effects of bioaccumulated toxicants in organisms include alterations of growth, reproductive success, competitive abilities and deformities such as imposex. Elevated toxicant concentrations in organisms (e.g. fish and shellfish) may also pose health risks to consumers of those organisms (including humans). For this reason, toxicant concentrations in food are regulated. There are still many challenges to understanding the fate, transport and interactions of contaminants in marine systems. In particular, more information is needed on contaminant concentrations and processes governing their distribution in Australian coastal environments (OzEstuaries).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

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Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Bioaccumulation – the process by which chemical are accumulated in biota with levels increasing up the food chain (i.e. small animals and plants take up toxicants from the waters, and when they are eaten by other animals, the toxicants move up the food chain with higher concentrations being found in higher predators).

Imposex – Development of male sex organs in females.

Spatial – Pertaining to space or distance.

Taxa – A taxonomic group of organisms (of any rank, e.g. species, genera, family) considered to be distinct from other such groups.

TBT – Tributyltin. A toxic chemical used to prevent the fouling of ship hulls.

Temporal – Pertaining to time.

7.27 Indicator: Toxicants in the sediment

Definition

This indicator documents the levels of toxicants in the surface sediments of estuarine, coastal and marine systems.

Rationale

Toxicants are chemicals that harm animals or plants. They can be natural (e.g. metals (zinc, copper) which are essential for life but become toxic at high concentrations) or unnatural (i.e. man-made substances). A list of potential toxicants is provided in the Water Quality Guidelines (ANZECC/ ARMCANZ, 2000a). Pollutants commonly accumulate in sediments and are a starting point for contamination throughout the food chain, potentially damaging marine life and affecting human health. 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 [plants] and fauna [animals] of the shallow-water ecosystems. Most toxicants find their way into the surface sediments of contaminated waterways after various periods (sometimes brief) in the water column. Areas with contaminated sediments may be harmful to humans, animals and plants (Ward *et al.*, 1998). For further information on toxicants including a detailed explanation of what toxicants are, the sources of toxicants, environmental significance of toxicants, and coastal habitats susceptible to toxicants see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Toxicants	<$100	Moderate	Moderate

Links to issues

- Animal kills and disease
- Biota (plants and animals) and habitat lost/ disturbed
- Dredging/ resuspension of toxicants from sediments
- Human health problems (skin irritations, disease, etc.)
- Point sources: industrial discharge, dumping of toxicants
- Poor water quality: toxicant levels
- Shellfish/ fisheries closures
- Toxicant release: spills, oil spills, insect control chemicals, pesticides/ herbicides, outboard motor emissions, etc.

Monitoring locations and frequency

The indicator would be monitored annually (or as otherwise specified in the SOP (Standard Operating Procedure) in a small number of carefully selected refuge/ reference areas (possibly nature reserves/ marine parks) and other randomly and explicitly selected sites. Development of the detailed techniques for an SOP will need a specialised assessment and pilot study for each site 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 (Ward *et al.*, 1998).

Data measurement methods

Detailed monitoring methods for toxicants in the sediment can be found in the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000a,b), guidelines for State of the Environment reporting (Ward *et al.*, 1998), and other scientific publications. Specific information is provided in OzEstuaries on pesticide hazard, industrial point source hazard, and wastewater discharges, which are useful for assessing toxicant risk from agricultural and/ or urban and industrial sources. This indicator would be measured using refined field sampling and laboratory analysis protocols to be defined and developed for a specific SOP (Ward *et al.*, 1998). It is recommended that sampling for toxicants be undertaken in accordance with the ANZECC/ ARMCANZ Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ ARMCANZ, 2000b). A recent approach involves not only an assessment of sediment quality, but also a determination of the severity of impact and identification of contaminant sources and dispersion pathways (OzEstuaries).

Data 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 (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 (Ward *et al.*, 1998). Many toxicants reaching estuaries have a high affinity for fine-grained sediment. The concentrations of some toxicants are therefore controlled to a certain extent by processes governing sediment transport and deposition. In tide-dominated waterways (e.g. deltas, estuaries and tidal creeks), flanking environments are the main traps for fine sediments, and these include mangroves (Harbison, 1986), saltmarsh areas (Lee and Cundy, 2001) and intertidal flats (Lee and Cundy, 2001). Fine sediments also accumulate in mangroves, saltmarsh and intertidal flats in wave-dominated coastal waterways (e.g. estuaries and strandplains/ coastal lagoons), but the central basin is usually the main sink. The baffling of water movement by seagrass leaves can also cause fine sediments and toxicants to deposit in seagrass meadows. Physical disturbance of these habitats (e.g. dredging, reclamation, erosion and re-suspension) can remobilise toxicants from the sediments into the water column (Lee and Cundy, 2001). DOM (dissolved organic matter) can enhance the solubilities of some organic pollutants and pesticides (Chiou *et al.*, 1986), and this might be important in areas where there is lots of decaying vegetation. There are still many challenges to understanding the fate, transport and interactions of contaminants in marine systems. In particular, more information is needed on contaminant concentrations and processes governing their distribution in Australian coastal environments (OzEstuaries).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* http://www.deh.gov.au/water/quality/nwqms/volume1.html

ANZECC/ ARMCANZ, 2000b. *Australian Guidelines for Water Quality Monitoring and Reporting.* http://www.deh.gov.au/water/quality/nwqms/monitoring.html

Chiou, C.T., Malcolm, R.L., Brinton, T.I. and Kile, D.E. 1986. Water solubility enhancement of some organic pollutants and pesticides by dissolved humic and fulvic acids. *Environmental Science and Technology* 20: 502-508.

Environment Protection Agency (EPA) (Queensland). 1999. *Water Quality Sampling Manual: for use in testing for compliance with the* Environmental Protection Act 1994. 3rd Edition. EPA, Queensland Government, Brisbane. http://www.epa.qld.gov.au/publications?id=330

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(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

Suchanek, T.H. 1994. Temperate coastal marine communities: biodiversity and threats. *American Zoologist* 34: 100–114.

Ward, T., Butler, E. and Hill, B. 1998. *Environmental indicators for national state of the environment reporting – Estuaries and the sea*. Australia: State of the Environment (Environmental Indicator Reports). 81 pp. Department of the Environment; Canberra. Website: http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

7.28 Indicator: Turbidity/ water clarity

Definition

This indicator documents the level of turbidity in estuarine, coastal and marine waters.

Rationale

Turbidity is a measure of water clarity or murkiness. It is an optical property that expresses the degree to which light is scattered and absorbed by molecules and particles. Turbidity results from soluble coloured organic compounds and suspended particulate matter in the water column. Suspended particulate matter may include clay and silt (e.g. suspended sediment), and detritus and organisms (OzEstuaries). 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. 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) (Ward *et al.*, 1998). For further information on turbidity and fine sediment loads including; a detailed explanation of what turbidity is, what causes turbidity, the significance of turbidity, coastal systems susceptible to turbidity, the impacts of fine sediment loads on coastal waterways and what biophysical parameters may indicate that a waterway is receiving excess sediment loads, see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics Sediment Quality	<$5 (Secchi/ NTU) <$30 (TSS) <$30 (turbidity tube; capital) >$1000 (turbidity meter; capital)	Easy	Moderate

Links to issues

- Algal blooms
- Biodiversity decreased
- Biota (plants and animals) lost/ disturbed (smothering, filter feeders, sessile benthic and grazing animals, physical abrasion of gills and behavioural changes, lower light availability for benthic plants)
- Diffuse sediment sources: catchment clearing, landuse and run-off (rural and urban)
- Dredging, trawling: resuspension of sediments, dumping of dredged material
- Environmental flows – water and frequency of floods from catchment water changed from natural by dams, barriers, water extraction, levees, impoundments and weirs, increased hard surfaces, land cover, decreased/ increased water velocity
- Episodic and large scale events (drought, floods, storms, cyclones, bushfires)

- Erosion
- Eutrophication
- Habitat lost/ disturbed (smothering)
- Light penetration decreased
- Poor water quality: turbidity
- Primary aquatic plant productivity (changed)
- Shipping movement through shallow waters
- Urban development and soil disturbance in coastal zone due to development
- Visual amenity decreased

Monitoring locations and frequency

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. 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. 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 two-tiered monitoring scheme is proposed comprising: intermittent sampling together with other water quality indicators; and continuous sampling at a master station. A sub-sampling approach could involve five sites sampled monthly. At each site, surface and bottom water samples would be collected and turbidity measured (Ward *et al.*, 1998).

Data measurement methods

Detailed monitoring methods for turbidity can be found in numerous publications including: the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), guidelines for State of the Environment reporting (Ward *et al.*, 1998), and other scientific publications. Turbidity sensors are well suited to automated monitoring systems. One of the five stations involved in the intermittent 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. Turbidity is being evaluated as a parameter able to be measured by remote sensing and if supported by selective ground-truthing, would be suitable for a national approach. It would also be advisable to pass a measured volume of water sample through a filter membrane (e.g. 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). The detail of a monitoring program will need to be developed and defined in an appropriate SOP (Standard Operating Procedure (Ward *et al.*, 1998). Turbidity is estimated either by nephelometry or by directly determining the mass of suspended particulate matter in given volume of sample. When 'turbidity' is directly determined (e.g. by filtration, drying and weighing) it is referred to as suspended particulate matter (SPM). By comparison, nephelometry compares the intensity of light scattered by a sample with the intensity of light scattered by a standard reference suspension under the same conditions. It is recorded in nephelometric turbidity units (NTU). Turbidimeters equipped with nephelometers are well suited to field measurement. Measures of visual clarity or light penetration are more appropriate for coastal and estuarine waters when the goal is estimate the depth of light penetration (Monbet, 1992). This is because turbidity levels (measured as NTU's) may be low in surface waters but may be high at the intersection between freshwater and seawater in a stratified water column. Visual clarity can be simply assessed by lowering a black and white circular plate (Secchi disk) into the water column. The depth at which the plate is no longer visible is called the Secchi depth. A simple rule of thumb is that light can penetrate to ~2-3 times the Secchi depth. Light sensors can be used for a more accurate measure of euphotic depth (i.e. the depth at which photosynthetically active radiation (PAR) is reduced to about 1%).

Data analysis and interpretation

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 highclarity waters loaded with aluminium arising from runoff from acid sulfate soils, can devastate biota. 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. 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. High turbidity levels can be the result of tidal current resuspending sediments, inputs from catchment/ shoreline erosion, dredging, dissolved organic matter and/ or algal blooms (Ward *et al.*, 1998). Further information on the interpretation of turbidity data can be found at the OzEstuaries website. Increased turbidity reduces the amount of light available for photosynthesis which may decrease the phytoplankton biomass and therefore result in increased dissolved nutrients in the water column. Turbidity caused by suspended sediment can smother benthic organisms and habitats, and cause mechanical and abrasive impairment to the gills of fish and crustaceans (ANZECC/ ARMCANZ, 2000b). Suspended sediment also transports contaminants (particulate nutrients, metals and other potential toxicants) (ANZECC/ ARMCANZ, 2000b), promotes the growth of pathogens and waterborne diseases, makes marine pests difficult to detect (Neil, 2002) and can lead to dissolved oxygen depletion in the water column if it is caused by particulate organic matter. Overall, unnaturally high turbidity levels can lead to a reduction in the production and diversity of species (OzEstuaries). Default trigger values for turbidity have been listed in the Water Quality Guidelines (ANZECC/ ARMCANZ, 2000a). The effect of total suspended solids on environmental conditions of waterways can be examined using the Simple Estuarine Response Model II (SERM II).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* http://www.deh.gov.au/water/quality/nwqms/volume1.html

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Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed. (nces.ed.gov/pubs2000/studenthb/glossary.asp).

Benthic – On the bottom of a body of water or in the bottom sediments.

Biomass – The total weight of all living organisms in a biological community or of a particular species/ group.

Eutrophication – The process of enrichment of water with nutrients that increase plant growth and the succeeding depletion of dissolved oxygen. A natural process that can be caused/ enhanced by an increase in nutrient loads or decreased flushing rates resulting from human activity.

Ground-truthing – To confirm remotely obtained data by physically visiting a site.

Impoundment – An accumulation of water into ponds/ dams by human-engineered blocking of natural drainage.

NTU – nephelometric turbidity units, measures relative intensities of light scatter

Secchi disk – black and white circular disk used to determine vertical turbidity

Sessile – Plants or animals that are permanently attached to a surface.

7.29 Indicator: Water-current patterns

Definition

This indicator reports on the change in water-current patterns within estuarine, coastal and marine waters.

Rationale

Estuarine, coastal and marine waters are constantly on the move. Ocean currents influence the environment of both aquatic and terrestrial ecosystems. Water flows in complex patterns of currents which are determined by the moon phase (tides), wind, salinity, temperature, bottom profile, riverine input, and the earth's rotation. Currents are important in determining the bottom topography and nature of a waterway. Strong currents scour the bottom preventing plant growth. As currents weaken they deposit sediments, building banks and sandbars. In addition to the movement of sediments, water currents are important in moving animals (e.g. plankton) and plants (e.g. seeds), nutrients, toxicants and other pollutants, as well as essential elements. Currents help maintain the balance of a system through the exchange of waters, and its contents, with adjoining systems. Human construction and actions, (e.g. bridges, piers, sea walls, canals, dredging, land reclamation, etc.), may cause a change in speed, gradient and direction of local current fields. This may have detrimental effects on the system (e.g. sea walls may halt the natural movement of sand, canals can reduce flushing rates of a system and result in eutrophication).

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics	<$5 (current meter) >$100 (drifters) >$1000 (capital)	Moderate	Moderate

Links to issues

- Climate change (changed rainfall patterns, global warming)
- Entrance modification (seawalls, spits, canals, etc.), dredging, artificial opening or closing of estuary mouth
- Environmental flows – water flows and frequency of floods from catchment water changed by dams, barriers, water extraction, levees, impoundments and weirs, landuse (increased hard surfaces, land cover), increased/ decreased water velocity
- Episodic and large scale events (drought, floods, storms, cyclones)
- Stratification of waters (change in mixing rates)

Monitoring locations and frequency

In general, the monitoring of this indicator will occur in estuarine and coastal areas where human induced changes to hydrodynamic are thought to be having detrimental impacts on the waterway. Annual monitoring, (covering the full tidal, etc. variation expected), would be sufficient for most studies. However, more frequent monitoring may be needed depending on the study and aspects of the management actions being monitored.

Data measurement methods

Detailed monitoring methods for water-current patterns can be found in numerous scientific publications. Water-current patterns can be monitored using a number of methods, including: moored conventional current meters, acoustics (sound), drifting buoys, or by tracing temperature or chemical properties of the water. The exact method used will depend on the aims of the monitoring study. Current measurements may be taken at a fixed location, transects or over a wide area. Moored instruments are used to obtain measurements at particular sites over a long time. Whereas, ship or satellite methods can make observations along a transect or over a wide area at a particular time. Conventional current meters measure current speed and direction via a rotor and vane. They can be moored in a fixed location and monitor continuously. Acoustic methods (e.g. Acoustic Doppler Current Profiler Systems (ADCP)), use echo sounders. These measure changes in the time it takes a sound pulse to travel through the seawater from floor to surface (or reverse) and return. Changes in the travel time are related to changes in water density, which are in turn related to changes in currents. Acoustic devices can be moored or attached to ships. Sea floor electrometers measure the average speed of an ocean current by sensing the electric field created by salty seawater moving through the Earth's magnetic field. Satellites can be used to monitor currents via drifter tracking, sea temperature or sea level. Satellite altimeters accurately measure the height of the sea surface. Because ocean currents cause the sea surface to slope (e.g. the sea surface is about a metre higher near Tasmania than it is near Antarctica), the altimeter provides a means of monitoring ocean currents from space (CSIRO, 2004).

Data analysis and interpretation

Estuarine, coastal and marine waters are constantly moving. In general, due to the highly variable nature of water-current patterns both temporally and spatially, initially there will be no standard data available to compare against. Results from initial studies will form the baseline data against which future results can be compared. A change in water-current pattern may result in several changes to the natural processes occurring within the system (e.g. residence times/ flushing rates, sedimentation/ erosion rates, animal migration, etc.), and thus adversely affect the waterway. It is important to try and determine if any observed changes in currents are natural or due to human impact. Changes in average air temperature (e.g. global warming) may affect water-current patterns at a regional scale.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2004. Southern Ocean and Antarctic Circumpolar Current. *CSIRO Marine Research, Media and Information: Information Sheets.* http://www.marine.csiro.au/LeafletsFolder/10ocean/10.html

Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

CSIRO – Commonwealth Science and Industry Research Organisation.

Impoundment – An accumulation of water into ponds/ dams by human-engineered blocking of natural drainage.

Spatial – Pertaining to space or distance.

Stratification – The layering of water due to differences in density.

Temporal – Pertaining to time.

Topography – Detailed study of the surface features of a region.

7.30 Indicator: Water soluble toxicants in the water column

Definition

This indicator documents the levels of water soluble toxicants in estuarine, coastal and marine waters.

Rationale

Toxicants are chemicals that harm animals or plants. They can be natural (e.g. metals (zinc, copper) which are essential for life but become toxic at high concentrations) or unnatural (i.e. man-made substances). A list of potential toxicants is provided in the Water Quality Guidelines (ANZECC/ ARMCANZ, 2000a). Most toxicants settle into surface sediments of contaminated waterways after various periods (sometimes brief) in the water column (Ward *et al.*, 1998). Waters containing water soluble toxicants may be harmful to humans, animals and plants. Heavy metals and other toxicants (including pesticides) were used as two determinants of water quality in the National Estuary Assessment (stage 2: modified estuaries) completed for the National Land and Water Resources Audit (NLWRA, 2002). For further information on toxicants including a detailed explanation of what toxicants are, the sources of toxicants, environmental significance of toxicants, and coastal habitats susceptible to toxicants see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Toxicants	<$100	Moderate	Moderate

Links to issues

- Animal kills and disease
- Biota (plants and animals) and habitat lost/ disturbed
- Dredging/ resuspension of toxicants from sediments
- Human health problems (skin irritations, disease, etc.)
- Point sources: industrial discharge, dumping of toxicants
- Poor water quality: toxicant levels
- Shellfish/ fisheries closures
- Toxicant release: spills, oil spills, insect control chemicals, pesticides/ herbicides, outboard motor emissions, etc.

Monitoring locations and frequency

Levels of water soluble toxicants should be monitored annually in a number of sites where toxicants are thought to be a threat, and control sites. However, the monitoring location will depend on aspects of the management actions being monitored. Standard operating procedures (SOPs) will need to be developed for the toxicants to be monitored and may require specialised assessment and pilot study for each site.

Data measurement methods

Detailed monitoring methods for toxicants in the water column can be found in the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000a,b), and other scientific publications. The Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ ARMCANZ, 2000b) give formal guidance for appropriate analytical methods for toxicants. Field sampling and laboratory analysis protocols need to be defined and developed depending on the specific toxicant to be monitored. It is recommended that sampling for toxicants be undertaken in accordance with the ANZECC/ ARMCANZ Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ ARMCANZ, 2000b). Decision tree frameworks for assessing toxicants in ambient waters are provided in those guidelines.

Data 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 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 (Ward *et al.*, 1998). Dissolved organic matter (DOM) can enhance the solubilities of some organic pollutants and pesticides (Chiou *et al.*, 1986), and this might be important in areas where there is lots of decaying vegetation. There are still many challenges to understanding the fate, transport and interactions of contaminants in marine systems. In particular, more information is needed on contaminant concentrations and processes governing their distribution in Australian coastal environments. The ANZECC Guidelines for Fresh and Marine Water Quality (ANZECC/ ARMCANZ, 2000a) lists several other deficiencies in knowledge.

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

ANZECC/ ARMCANZ, 2000a. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* http://www.deh.gov.au/water/quality/nwqms/volume1.html

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Environment Protection Agency (EPA) (Queensland). 1999. *Water Quality Sampling Manual: for use in testing for compliance with the* Environmental Protection Act 1994. 3rd Edition. EPA, Queensland Government, Brisbane. http://www.epa.qld.gov.au/publications?id=330

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(*OzEstuaries*). Radke, L.C., Smith, C.S., Ryan D.A., Brooke, B., Heggie, D. and contributors. 2003. Coastal Indicator Knowledge and Information System I: Biophysical Indicators. Web document. Canberra: Geoscience Australia. http://www.ozestuaries.org/indicators/indicators.html

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Glossary

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Spatial – Pertaining to space or distance.

Temporal – Pertaining to time.

Toxicant – natural or synthetic chemicals that are harmful to plants and animals.

7.31 Indicator: Water temperature

Definition

This indicator reports the temperature of estuarine, coastal and marine waters.

Rationale

Water temperature regulates ecosystem functioning both directly through physiological effects on organisms, and indirectly, as a consequence of habitat loss (ANZECC/ ARMCANZ, 2000b). Photosynthesis and aerobic respiration, and the growth, reproduction, metabolism and the mobility of organisms are all affected by changes in water temperature. Indeed, the rates of biochemical reactions usually double when temperature is increased by 10°C within the given tolerance range of an organism (ANZECC/ ARMCANZ, 2000b). This is called the Q10 rule, and it also applies to microbial processes such as nitrogen fixation, nitrification and denitrification. If temperature exceeds the tolerance range for a given taxon (e.g. fish, insects, zooplankton, phytoplankton, microbes), its ability to survive may be compromised. For example, coral species live within a relatively narrow temperature range, and positive or negative temperature anomalies of only a few degrees can induce bleaching (Hoegh-Guldberg, 1999). Unnatural changes in water temperature are a suggested indicator of water quality in the ANZECC and ARMCANZ guidelines (ANZECC/ ARMCANZ, 2000b). Changes in water temperature influence:

- oxygen and calcium carbonate solubility (e.g. dissolved oxygen levels)
- toxicant absorption
- toxicity of some chemicals (natural or man made)
- viral persistence
- density
- conductivity
- pH
- partial pressure of CO2
- saturation states of minerals

For further information on the effects of temperature on waterways including a detailed explanation of what causes water temperature to change, the significance of water temperature, and coastal waterways most susceptible to unnatural changes in water temperature see the OzEstuaries website.

Key information

Information on the level of complexity needed to (1) collect the data, and (2) analyse and interpret the data are also provided in the table below. 'Easy' complexity would mean that a person with little experience could easily learn how to collect/ interpret the data. 'Moderate' would require a person with a couple years experience, and 'hard' would require an expert with several years of experience.

Stressors this indicator is recommended for:	Estimated Cost per sample	Complexity – data collection	Complexity – data interpretation and analysis
Hydrodynamics	<$5 <$100 (thermometer; capital) <$500 (temperature data logger; capital)	Easy	Moderate

Links to issues

- Biota (plants and animals) lost/ disturbed
- Climate change/ global warming (increased air temperature)
- Coral bleaching
- Industrial, dam and municipal discharge (hot or cold water)
- Poor water quality: water temperature
- Water stratification (thermoclines; poor water column mixing)
- Water-current pattern (changed)

Monitoring locations and frequency

Sites threatened by water temperature change should be monitored, however, the monitoring location will depend on aspects of the management actions being monitored. For example, if monitoring for water temperature change resulting from climate change, then monitoring will occur in all estuarine, coastal and marine waters to determine the annual variability of surface waters. If monitoring industrial sources then specific 'threatened' sites and controls will be selected. Different depths at a location may also need to be monitored. The frequency of monitoring will depend on what management actions are being monitored. Water temperature can be monitored continuously or during/ after specific events. Water temperature changes daily and seasonally. Therefore, continuous monitoring of water temperature using a moored, continuously recording thermometer is advisable. However, if this is not possible then water temperature should be measured at dawn and midday to allow for diurnal variation.

Data measurement methods

Detailed monitoring methods for water temperature can be found in numerous publications including: the Monitoring Guidelines (ANZECC/ ARMCANZ, 2000b), guidelines for State of the Environment reporting (Ward *et al.*, 1998), and other scientific publications. It is generally good practice to measure temperature when taking any physical, chemical, or biological samples. Temperature measurements are usually made with a mercury thermometer with 0.1°C increments. Temperature loggers can also be deployed to measure and record temperatures at different depths and at specified time intervals (OzEstuaries). Thermal satellite imaging can be used to examine the temperature of large areas of ocean, which may have increased in temperature as a result of climate change.

Data analysis and interpretation

Water temperature in coastal areas changes naturally, as part of daily and seasonal cycles, with variations in air temperature, currents, and local hydrodynamics. Long-term monitoring of water temperature provides insight into seasonal and inter-annual temperature cycles, as well as into temperature anomalies caused by human activities (OzEstuaries). Changes to water temperature can result from the following (see OzEstuaries):

- Changes to freshwater flow and freshwater/ marine water mixing by winds or tides;
- Industrial discharges ('cooling' waters from power plants); and,
- Changes in air temperature and currents in response to El Niño or global warming.

Sudden or large changes in temperature are generally of concern in coastal areas. Large temperature differences between surface and bottom waters are indicative of stratification (OzEstuaries). Default trigger values for water temperature are not given in the Water Quality Guidelines. They recommend the development of local objectives for upper and lower low-risk trigger values defined by the 20th percentile and 80th percentile of the reference distribution. However, the Water Quality Guidelines do report that to protect aquaculture species, water temperature should not change by more than 2.0°C in 1 hour (ANZECC/ ARMCANZ, 2000a).

Data storage

Data should be stored by agencies and by the collectors (if different) of the data. The data, or a summary of the data at minimum, should be held in a metadatabase accessible to any party conducting water quality monitoring.

References and further information

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Ward, T., Butler, E. and Hill, B. 1998. *Environmental indicators for national state of the environment reporting – Estuaries and the sea*. Australia: State of the Environment (Environmental Indicator Reports). 81 pp. Department of the Environment; Canberra. Website: http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

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Glossary

Aerobic – In the presence of oxygen.

Baseline data – Information collected to comprise a reference set for comparison of a second set of data collected at a later time; used to interpret changes over time usually after some condition has been changed.

Spatial – Pertaining to space or distance.

Stratification – The layering of water due to differences in density.

Temporal – Pertaining to time.