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Review and current synthesis of estuarine, coastal and marine habitat  
monitoring in Australia

Report to the National Land & Water Resources Audit

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April 2008





# Preface

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This report is an advisory document that has been commissioned by the National Land & Water Resources Audit (the Audit) and prepared by the University of Tasmania.

The report, *Review and current synthesis of estuarine, coastal and marine habitat monitoring in Australia*, is not intended to be an exhaustive review. It brings together fundamental information to inform the Audit regarding monitoring and assessment of benthic marine habitats across Australia under the National Natural Resource Management (NRM) monitoring and evaluation framework (National M&E Framework).

The document provides:

- A list of all current estuarine, coastal and marine habitat monitoring projects
- A summary of the spatial and temporal coverage for different habitats
- An overview of how different habitats are monitored to identify where common approaches or methodologies may allow broad-scale or regional assessments of habitat condition for the purpose of NRM reporting.

# Executive summary

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Australia's marine, coastal and estuarine environments support a diverse array of benthic habitats ranging from hard reef to soft-sediment substrates. These habitats support a diversity of biological communities and ecological functions; which in turn provide a range of important ecosystem services (e.g. refuge and structure for associated organisms, nutrient cycling and protection against coastal erosion). However, despite their acknowledged importance there is no coordinated national strategy for monitoring the status and condition of these benthic habitats. Monitoring, where it is undertaken, is often fragmented and short term in nature and typically there are few or no national standards for either the collection of monitoring data or the reporting of results. This situation currently severely impairs efforts to report on habitat condition and produce broad regional scale assessments about the status of a range of habitats across Australia.

This review is intended to provide a broad overview of monitoring across Australia including: 1) who is undertaking what monitoring and where, 2) what is being monitored (in terms of indicators and specific parameters), and 3) whether and how this is interpreted and assessed for reporting purposes. The review covers, where possible, all major benthic habitat types including coral reefs, subtidal and intertidal rocky reefs, seagrass beds, mangroves and unvegetated soft-sediments. Specifically, the review identifies where gaps in monitoring currently exist, and where current monitoring programs may permit broad regional assessments of benthic habitat condition.

The review found that there are substantial gaps in monitoring across Australia both in terms of habitat and geographic coverage. Whilst there is a preponderance of reef monitoring (both coral and temperate rocky), a range of other benthic habitat types are under-represented. Specifically, there appears to be little monitoring of soft-sediment habitats such as mud flats, sandy/muddy bays and beaches. There is also little formal monitoring of vulnerable (to climatic change) intertidal habitats such as mangroves, saltmarsh and intertidal rocky reefs. Moreover, where benthic habitats are monitored geographic coverage may be limited in extent.

This review has also highlighted some logical difficulties in producing rigorous condition assessments due to deficiencies in design or insufficient temporal data. Many current monitoring programs are not designed to assess the condition of benthic habitats, but to monitor outbreaks of destructive species, collect compliance data such as species inventories and baseline information and/or assess the performance of the implementation of MPAs. This further diminishes attempts to derive broadscale ecological condition assessments. Other difficulties arise where methods are compatible, but the data upon which assessments are based, are not. This may also be a problem for projects which construct historical trends and past patterns using aerial photo records to measure change in habitat extent. Where historical patterns are inferred from only a small number of data points, caution should be exercised when interpreting such patterns. However, such information does provide an important context for current monitoring efforts, particularly where there is an emphasis on the recovery of degraded habitats (e.g. seagrass).

Broadscale regional assessments are currently possible for coral reefs and seagrasses within the Great Barrier Reef World Heritage Area (GBRWHA), Queensland. There is also good information on seagrass condition close to Adelaide, Perth, Melbourne and

Brisbane. However, very different methods are used to monitor seagrasses in each of these regions. In contrast, similar methodologies are used to monitor subtidal temperate reef habitats across southern Australia. There is excellent monitoring coverage of Tasmanian subtidal reefs with a range of other locations, generally coinciding with MPAs, spread across southern Australia. However, this information is currently not used to assess reef condition *per se*, but to test the performance of MPAs. Information about the status of other regions and habitats across Australia is severely lacking.

Overall, these monitoring programs relay a good story about the health of Australian marine benthic habitats. Seagrass and coral cover appears to be stable in the GBRWHA for the past ~ 15 years, although it is too early to make assessments about the condition of inshore reefs where greater degradation may be expected. Elsewhere seagrass declines appear to have stabilized relative to historical trends, commensurate with improvements in nearshore water quality. However, recolonisation of denuded areas is slow. There also appears to be some recent losses in Victoria, however, it is unclear whether this is a natural pattern. In general, temperate reefs appear to be in good health throughout southern Australia. Where protection is provided, fished species recover quickly and only a small number of reefs, off the metropolitan coast of Adelaide, have actually been found to be significantly degraded. Where information exists for mangroves, populations appear to be stable and have even increased in extent relative to lows in the 1970s.

However, caution should be exercised when attempting to extrapolate such broad assessments to the health of marine benthic environments more generally because of the significant number of gaps in geographic and habitat coverage that exist. To overcome this hurdle will require an increased investment in monitoring, particularly for intertidal habitats, better co-ordination of existing projects and greater focus on designing or re-designing (where possible) studies so that habitat condition can be explicitly assessed.

# 1. Introduction

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## 1.1 Background

Coastal zones are under unprecedented pressure as a consequence of increasing population growth, urban development and the alteration of estuarine and catchment processes. Australia's population is expected to grow by 60% to 33 million by 2051 (ABS 2005). More than 90% of this increase will be in and around major centres of the coastal zone. Environmental impacts associated with coastal developments can be significant and cumulative and may continue over an extended time frame. Accordingly, there is a need to monitor the status of coastal and marine environments in order to effectively manage future and on-going impacts.

Human impacts to nearshore coastal and marine environments have been well documented elsewhere and will not be covered in detail here (see Zann and Sutton 2000). They include (but are not limited to): 1) elevated inputs of nutrients and sediments altering coastal primary productivity, 2) destruction and degradation of coastal habitats (e.g. via dredging, drainage and coastal development), 3) removal of species and biomass through fishing activities altering the trophic structure of nearshore marine food-webs by selectively removing trophic levels, and through the often indiscriminate release of fishing by-catch, 4) input of chemicals (pesticides/herbicides) and heavy metals from agriculture and industry, 5) introduction and spread of exotic species/pests and 6) introduction of human litter (waste products).

Managing these human impacts is likely to become increasingly complex against the backdrop of forecast climatic changes. Climate change is predicted to increase sea levels and temperatures, alter sea chemistry and modify oceanographic processes (currents, mixing etc) (Poloczanska et al. 2007). However, there is great uncertainty about how such climatic changes will affect marine ecosystems. Moreover, there are fears that such changes will adversely interact with a range of pre-existing human impacts (most notably fishing, coastal development and nutrient inputs) further degrading coastal environments. Prudence dictates that there is a need to reduce and manage human impacts wherever possible and set aside areas free of human impacts to protect areas of high conservation value.

Most efforts to conserve areas of high conservation value in nearshore coastal environments have tended to focus on conserving representative areas of coastal habitat. In part, this is because habitats are often clearly recognizable biomes that support important ecological functions (ecosystem services). The nature of these functions varies between habitat types, but in general benthic habitats are important local sources of primary production and nutrient cycling and provide physical refuge for a range of organisms. Moreover, seagrass and mangroves communities play important roles in stabilizing substrates and protecting coasts from coastal erosion. Destruction of coastal habitats thus has the potential to degrade the ecosystem services they provide by impairing function and diminishing biodiversity.

Monitoring of coastal and marine habitats at the national level has some serious challenges. While significant progress is currently being made to collate information on the extent and distribution of key habitats, there are few accepted approaches for reporting on the

condition of marine and coastal habitats. Where monitoring of condition is undertaken it is often fragmented, short term and typically there are few or no national standards for either the collection of monitoring data or for the reporting of the results. This makes comparison of results across state boundaries difficult at best.

## 1.2 Aims

This review aims to collate all existing information on monitoring of the condition of estuarine, coastal and marine benthic habitats across Australia. This covers, where possible, all major benthic habitat types including coral reefs, subtidal and intertidal rocky reefs, seagrass beds, mangroves, unvegetated subtidal sediments and beaches. This project aims to provide the National Land and Water Resources Audit and researchers in the field with a broad overview of monitoring across Australia including collecting critical information on who is undertaking what monitoring and where, what is being monitored (in terms of indicators and specific parameters) and whether and how this is being interpreted and assessed for reporting purposes. This information is collated into a single database and forms the basis of an evaluation to determine whether the synthesis of such material at a national or regional level will allow valid broad-scale assessments of the condition of key marine and coastal habitats.

For the purpose of this review we broadly define monitoring as routine or systematic measurement of biological or physical parameters for the purpose of a) assessing the ecological state of an ecosystem, b) detecting and assessing human impacts, and c) evaluating responses following mitigation of impacts or restoration. Mapping is not monitoring *per se*, unless it is repetitive and of sufficient resolution to detect change, nor are one-off biodiversity surveys except, possibly, where suitable reference sites are incorporated into the sampling design. I have also restricted this review to broadscale monitoring programs where possible, and do not include a plethora of monitoring programs designed to address very specific and often localized impacts (e.g. marina developments or sewage outfalls). Such monitoring projects rarely relay information about the condition of habitats beyond the impacted sites considered.

Specifically, this review will provide:

1. A list of all current estuarine, coastal and marine habitat monitoring projects (listed by habitat and state). For the purpose of this review I have defined current as either ongoing or undertaken with the last 3-4 years. This is to ensure that only up-to-date information is used in the review, particularly in regards to reporting existing assessments.
2. A summary of the spatial coverage for different habitats and by extension identify where gaps exist.
3. An overview of how different habitats are monitored across Australia. Specifically, the review identifies where common approaches or methodologies may permit broad-scale or regional assessments of habitat condition as part of national NRM reporting.

Note this review is not intended to be a critical assessment of the methods and indicators used to monitor habitats as this is beyond the scope of the project and the expertise of the author.

## 2. Methods

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The list provided is not intended to be definitive, nor is it exhaustive given the time-constraints of the project, but includes all major habitat monitoring projects currently undertaken in Australia.

Project proponents were asked to provide the following information:

1. The generic location of the project?
2. Who is undertaking the work including current contact details?
3. Many monitoring programs are undertaken against the backdrop of perceived human impacts. Could you indicate, where relevant, what these impacts are?
4. What exactly is being monitored/measured (i.e. range of methods and indicators used)?
5. Duration of project (indicating whether on-going or not)?
6. What is the spatial coverage of the assessment (e.g. how many sites are monitored)?
7. How often are sites monitored?
8. What is the approach used to assess change (reference sites/regions or trigger levels or trend analysis)?
9. How often are formal assessments made or published by the agency?
10. What was the outcome of formal assessments?

The first three questions relay who is undertaking the work and what is the context of the work, particularly in relation to perceived human impacts. The next five questions (3–8) address how assessments are made and on what level of data these assessments are based. Question eight asks on what logical basis, assessments are derived. Where human impacts are implicated monitoring projects aim to detect departure from ‘natural conditions’ and by extension identify when and where human impacts have occurred. There are three broad approaches that can be used to achieve these aims: 1) trend analysis (monitoring changes over time), 2) use of ‘unimpacted’ reference sites or regions as a comparative tool, and 3) setting of levels using information derived from literature or previous studies against which anomalous events can be identified. The best example of the latter is the ANZECC guidelines used for water quality assessment; although it is not immediately clear how this approach would be used to assess habitats. Generally these guidelines provide a normal range of values within which a parameter is expected to occur.

The validity of condition assessments is also closely related to the data sources used. This is clearly the case for trend analysis where longer term data sets provide greater confidence in inferring trends (e.g. > 10 years) and distinguishing natural cycles from anthropogenic impacts. Similarly, greater spatial coverage allows projects to make assessments across broader spatial scales. This is important when the impacts of interest are spatially diffuse in nature (e.g. agricultural inputs, climate change).

Question nine asks whether formal assessments are produced and whether these are published and question 10 asks the project proponents to summarize the most recent assessment outcomes. These last two points are important, because often environmental monitoring does not proceed to this stage. That is, monitoring is undertaken without any formal (and thus critical) assessment being made. All this information is summarized in a database accompanying this report. Summaries of this information are provided throughout the review (Tables 1–5).

## 3. Review

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Table 1 lists 23 monitoring projects identified in the course of this review. Excluded were one-off marine biodiversity assessments (numerous) and a number of recently undertaken baseline studies intended as platforms for future monitoring projects (e.g. projects in north-west WA associated with gas and oil exploration and extraction). Also excluded were smaller monitoring programs that were specifically designed to detect localized impacts on habitats (e.g. monitoring of benthos adjacent to fish cages) – these may tell us much about impact *per se*, but little about the general condition of the benthos.

### 3.1 Geographic coverage of habitat monitoring

The most commonly monitored benthic habitats were reefs, either coral (7 studies) or temperate subtidal (6), and seagrass (7) (Table 1). This emphasis on reefs is likely to grow further as a number of planned monitoring projects (2 in northern WA (DEC, AIMS) and 1 in NSW (DPI)) are also reef based. In the southern states the emphasis on reefs has been entirely subtidal and there are no comparable current programs for intertidal reefs, despite their prevalence along the southern coast. Intertidal environments are likely to be most vulnerable to climatic changes (via sea level rise, increased air temperature and storm frequency) and thus it is concerning that there are no existing monitoring programs or baseline datasets for these communities. Tim O’Hara (Museum Victoria) is developing tools to monitor intertidal reef health in Victoria and a number of longer term monitoring projects have been conducted in the past (e.g. Keough and Quinn 1998). Robert Black (University of WA) and Tony Underwood (Sydney University) also have ongoing long-term projects (> 30 yrs) which may serve of as useful baseline data sets. Tim Glasby (NSW DPI) has indicated that NSW will begin to monitor intertidal rocky reefs more broadly from 2008 onwards.

Seagrass monitoring also features prominently (7 studies). Seagrass is an important habitat, most notably for the juveniles of commercial fish species, but historically seagrass cover has diminished significantly. This has been most evident for coasts and embayments adjacent to population centres. For example, 80% of seagrass cover has been lost in Cockburn Sound, Western Australia and an estimated 5000 hectares of seagrass has been lost off the Adelaide coastline since 1935. Many seagrass monitoring programs are consequently located in regions where there have been historical declines in seagrass cover and where water quality is poor, notably, the Adelaide and Perth Metropolitan coastlines, Port Phillip Bay and south-east Queensland including Morton Bay.

By comparison, there are substantially fewer monitoring projects conducted in a range of other important benthic habitats, most notably soft-sediment environments. These environments are often viewed as a barren matrix which surrounds more diverse and functionally important habitats (i.e. reefs and seagrass) – both points are contestable. With the exception of the monitoring of soft-sediment and epifaunal (sponges, bryozoans) communities in the Benthic Protection Zone proclaimed in the Great Australian Bight

Table 1. Monitoring projects included in this review listed by habitat.

State	Habitat	Project	Agency/Proponent	Contact person
NT	Coral	Monitoring of coral reefs at Cobourg Peninsula	Marine Biodiversity Group, NRETA	Victor Gomelyuk
Qld	Coral	Long-term GBR monitoring program (GBR LTMP)	Australian Institute of Marine Science	Hugh Sweatman
Qld	Coral	Inshore coral reef demography and assessment	Australian Institute of Marine Science	Britta Schaffelke
Qld	Coral	Ecosystem Health Monitoring Program	Qld EPA, Freshwater and Marine Sciences Group	David Rissik
WA	Coral	Ningaloo Marine Park <i>Drupella</i> long-term monitoring program	DEC WA Marine Science Program	Shannon Armstrong
WA	Coral	Dampier Archipelago long-term monitoring project	DEC WA Marine Science Program	Shannon Armstrong
WA	Coral	Recovery of coral communities in Bill's Bay, Ningaloo Marine Park (1989–2006)	DEC WA Marine Science Program	Suzanne Long/Shannon Armstong
Qld	Mangroves	Port Curits Mangrove Monitoring Program	Central Queensland University	Alistair Melzer
NT	Mangroves and associated coastal vegetation	Mangrove change in Darwin coastal swamps	Charles Darwin University	Guy Boggs/Grant Williamson
NSW	Seagrass, mangrove and saltmarsh	Broadscale monitoring of seagrass, saltmarsh and mangroves in NSW estuaries	NSW Department of Primary Industries	Rob Williams
Qld	Seagrass	Seagrass habitats in GBR World Heritage Area	QDPI	Rob Coles
Qld	Seagrass	Ecosystem Health Monitoring Program	Qld EPA, Freshwater and Marine Sciences Group	David Rissik

VIC	Seagrass	Victorian multi-regional seagrass assessment	Fisheries Victoria	Dave Ball
VIC	Seagrass	Seagrass monitoring at Blairgowrie, Port Phillip Bay	Fisheries Victoria	Dave Ball
WA	Seagrass	Seagrass health monitoring – Perth metropolitan region	Edith Cowan University	Paul Lavery
SA	Seagrass	Nearshore seagrass change along the Adelaide metropolitan coast	SA EPA	Sam Gaylard
SA	Sediments/epifauna	Benthic Protection Zone monitoring project	SARDI	Dave Currie
NSW	Subtidal subtropical reef/coral	Monitoring of Solitary Islands Marine Park	NSW Marine Parks Authority	Macolm Hammish
NSW	Subtidal temperate reef	Nearshore reef monitoring; Northern NSW	National Marine Science Centre, University of New England	Steve Smith
SA	Subtidal temperate reef	Health of subtidal reef environments in South Australia	SA EPA	Greg Collings/Jason Tanner
Southern Aust.	Subtidal temperate reef	MPA ecological monitoring	University of Tasmania	Graham Edgar
TAS	Subtidal temperate reef	Condition of Tasmanian rocky reef communities	University of Tasmania	Neville Barrett
VIC	Subtidal temperate reef	Victorian MPA monitoring	Parks Victoria	

(SARDI) there are no current soft-sediment monitoring projects. The inclusion of this project is perhaps an anomaly as it is not intended as an ongoing monitoring project, but rather as a test of the effectiveness of the protection zone (see also temperate reef habitats).

Probably, the best example of where the condition of soft-sediment environments has been assessed at a large spatial scale over a long time-frame is the Port Phillip Bay Environmental Study (PPBES). This study, first undertaken in the 1970s and then repeated in the 1990s, focused primarily on the sedimentary basin which dominates PPB and considered the impact and fate of nutrients released into the Bay. Wilson et al. (1998) documented significant changes in Port Phillip Bay benthic invertebrate communities from 1969 through to 1995 consistent with an overall improvement in the health of the Bay relative to the 1970s. There are, however, no plans to repeat this work.

Soft-sediment environments dominate coasts and estuaries around Australia in terms of overall coverage. They are important sites for the storage and recycling of nutrients and in some places support spectacular epifaunal assemblages (e.g. sponge gardens) and demersal fisheries, yet they receive far less emphasis than a range of other benthic habitats.

This review only identified three mangrove monitoring studies. Only one of these studies (Port Curtis mangrove study) measured changes in the structure of mangrove forest at small spatial scales. The other two studies (from the NT and NSW) measured change in mangrove extent over time using aerial photo records. In NSW changes in the extent of mangrove, saltmarsh and seagrass habitats in estuaries were measured in combination based on the belief that these three intertidal habitat types are linked. This is the only saltmarsh monitoring in the country.

Only one project, the MPA monitoring project undertaken by Graham Edgar (University of Tasmania), spans state borders. This project is run with the assistance of state government departments notably DEC (WA), DEH (SA) and NSW Parks. However, it is also likely that the coral reef monitoring undertaken by AIMS in the Great Barrier Reef World Heritage Area (GBRWA) will expand to include reefs in northern and north-western Australia in coming years.

### **3.2 Perceived impacts**

The most commonly cited human impact was elevated nutrient and sediment inputs (11 studies), followed by fishing impacts (7 studies). Elevated nutrient levels were most commonly cited as a rationale for seagrass monitoring, whereas fishing was often cited as a perceived impact for reef (coral or temperate) based projects (Table 2). It is no coincidence that a number of subtidal reef monitoring projects in temperate Australia are associated with the proclamation of marine protected areas (MPAs). The primary aim of these areas is to reduce fishing pressure in addition to protecting these areas from other threats). One study (MPA ecological monitoring – G Edgar) was designed specifically to assess how well MPAs perform in terms of protecting reef biodiversity in temperate reef environments. This project initially began in Tasmania, but has subsequently grown to include other locations across southern Australia from Lord Howe Island to Jurien Bay (Western Australia) as other MPAs have come online.

Table 2. Perceived impacts supplied as rationales for monitoring of benthic marine habitats.

State	Habitat	Project	Location	Impacts
NT	Coral	Monitoring of coral reefs at Cobourg Peninsula	Cobourg Peninsula, Arafura Sea, NT	Shallow reefs are susceptible to thermal stress and consequently bleaching (via climate change)
Qld	Coral	Long-term GBR monitoring program (GBR LTMP)	Great Barrier Reef	Human visitation, fishing, climate change, crown-of-thorn starfish outbreaks (possibly linked to human activities)
Qld	Coral	Inshore coral reef demography and assessment	Inshore Great Barrier Reef from Daintree to Keppel Bay	Diffuse land run-off, input of nutrients and sediments from agricultural activity in the catchments adjacent to the GBR
Qld	Coral	Ecosystem Health Monitoring Program	Estuaries and embayments, b/w Noosa and Currumbin, SE Qld	Diffuse land run-off, input of nutrients and sediments from agricultural activity and urban development
WA	Coral	Ningaloo Marine Park <i>Drupella</i> long-term monitoring program	Ningaloo MNP, NW WA	<i>Drupella</i> (a corallivorous gastropod) populations may be influenced by fishing pressure
WA	Coral	Dampier Archipelago long-term monitoring project	Dampier Archipelago, NW WA	Recreational fishing; oil and gas industry activities and infrastructure development
WA	Coral	Recovery of coral communities in Bill's Bay, Ningaloo Marine Park (1989-2006)	Bill's Bay, Ningaloo Reef, WA	Study follows recovery of corals in shallow bay in response to a natural anoxic event resulting in a 100% mortality event (1989)
Qld	Mangroves	Port Curtis mangrove monitoring program	Port Curtis, Gladstone	Reclamation of adjacent tidal wetland areas
NT	Mangroves and associated coastal vegetation	Mangrove change in Darwin coastal swamps	Greater Darwin area and adjacent Shoal Bay	Effluent from sewage treatment plant and drainage (as part of mosquito control)
NSW	Seagrass, mangrove and saltmarsh	Broadscale monitoring of seagrass, saltmarsh and mangroves in NSW estuaries	All estuaries in NSW	Land use changes (elevated inputs of nutrients/sediments), changes to river flows and hydrology, dredging and land reclamation
Qld	Seagrass	Seagrass habitats in GBR World Heritage Area	Cape Yorke – Burdekin R.	Increased sediment/nutrient loads (agriculture), herbicides, coastal development and climate change (future)

Qld	Seagrass	Ecosystem Health Monitoring Program	Estuaries and embayments, Noosa - Currumbin, SE Qld	Diffuse elevated inputs of nutrients/sediments linked to rapid urban development
VIC	Seagrass	Victorian multi-regional seagrass assessment	Port Phillip Bay, Western Port and Corner Inlet	Diffuse elevated inputs of nutrients/sediments from urban and agricultural areas
VIC	Seagrass	Seagrass monitoring at Blairgowrie, Port Phillip Bay	Blairgowrie, Port Phillip Bay	Catchment runoff from urbanised areas (nutrients/sediments), localised damage from boat anchorage
WA	Seagrass	Seagrass health monitoring – Perth metropolitan region	Perth Metropolitan coast, including Cockburn Sound	Nutrient enrichment and elevated suspended solids in the nearshore environment
SA	Seagrass	Nearshore seagrass change along the Adelaide metropolitan coast	Adelaide Metropolitan coastal waters	Nutrient enrichment and elevated suspended solids in the nearshore environment
SA	Sediments/epifauna	Benthic Protection Zone monitoring project	BPZ, Great Australian Bight (40 km strip extending 390 km offshore)	Demersal trawling is prohibited within the BPZ due to potential impacts on benthic communities thus providing an insight into impacts of trawling for sites outside this zone
NSW	Subtidal subtropical reef/coral	Monitoring of Solitary Islands Marine Park	Solitary Islands, Nthn NSW	Human visitation, fishing, climate change, subtropical white syndrome coral disease
NSW	Subtidal temperate reef	Nearshore reef monitoring; Northern NSW	Northern NSW; Port Macquarie – Tweed R.	Rapid urban development: marine debris, sedimentation and urban run-off (nutrients)
SA	Subtidal temperate reef	Health of subtidal reef environments in South Australia	Adelaide coastal waters, SA coastal waters (Gulfs etc)	Reefs closest to metropolitan Adelaide impacted by increased nutrients (wastewater and stormwater), sedimentation and turbidity. Fishing may also exert an influence.
Sthn Aus	Subtidal temperate reef	MPA ecological monitoring	Inshore reefs situated within and adjacent to MPA reserves	Fishing (recreational and commercial), introduced species, climate change
TAS	Subtidal temperate reef	Condition of Tasmanian rocky reef communities	Inshore reefs around Tasmania	Fishing (recreational and commercial), introduced species, climate change
VIC	Subtidal temperate reef	Victorian MPA monitoring program	MPAs along the Victorian Coastline	N/A

Seagrasses require relatively clear waters and are generally restricted to shallow waters. Elevated run-off of nutrients, sediments and to a lesser extent, herbicides, have commonly been implicated in the dieback of seagrass meadows mediated by increases in turbidity and (algal) epiphytic loads leading to reductions in ambient light levels and increased physiological stress. At smaller spatial scales boating and shipping activities (e.g. propeller and anchor damage) may damage seagrass beds and prevent recolonisation of seagrass. Elevated nutrient and sediment inputs were also cited as a rationale for monitoring of inshore coral reefs in the GBRWHA and for temperate reefs located off the Adelaide metropolitan coast. For the latter, nutrients and sediments have been implicated in the loss of brown macroalgae on northern coastal reefs, adjacent to Adelaide (Cheshire et al. 1998).

The other notable rationale for monitoring cited was the impact associated with the spread of introduced species, but also changes to the natural population dynamics of native species that are known agents of degradation on reef communities (most notably the coral-feeding *Acanthaster planci* (crown-of-thorns starfish) and the gastropod mollusc *Drupella* sp.). Monitoring outbreaks in the populations of these coral feeding invertebrates is a major role of both the long-term GBR monitoring program and the Ningaloo reef monitoring project conducted by DEC in Western Australia. *Acanthaster planci* outbreaks have recently been linked to nutrient run-off (Brodie et al. 2004) highlighting that many of the impacts considered are inter-related. Changes to the range of the long-spined urchin *Centrostephanus rodgersi* along the east coast of Tasmania should also be included in this list. Formerly, restricted to the south-east coast of mainland Australia, since the mid 1970s this species has spread (naturally) south, transforming macroalgal-dominated subtidal reefs into denuded urchin barrens.

Climate change was also commonly cited as a rationale for continued monitoring, presumably with the aim of detecting future changes where they occur. The ecological consequences of climatic change are currently not well understood for marine systems and so existing monitoring programs may provide early clues to how climatic changes may be manifested in a range of ecosystems. Stuart-Smith et al. (2008) documented few changes in rocky reef assemblage structure around Tasmania between 1993 and a resurvey in 2006, despite significant warming recorded of the east coast of Tasmania. Coral bleaching events are often cited as a current and ongoing manifestation of climate change. However, bleaching events may be difficult to detect without fine scale temporal sampling as most bleaching events are ephemeral allowing corals to fully recover. Most monitoring of coral bleaching to date has used remote sensing techniques where risk is assessed using sea-surface temperature data. Permanently bleached and hence dead coral, however, can be measured from year to year (see below in regards to frequency of sampling).

### 3.3 How are habitats monitored?

#### 3.3.1 Coral reefs

The Australian Institute of Marine Science (AIMS) has been very influential in establishing standardized monitoring protocols for coral reefs. Where coral reef monitoring programs have been developed elsewhere (notably in NW Western Australia) this has often been by AIMS trained or influenced scientists. The most comprehensive coral monitoring program in Australia is the long-term GBR monitoring program (LTMP) lead by Hugh Sweatman. This program has coral reef monitoring data dating back to 1986 (Table 3). The most recent assessment this program surveyed 99 reefs (using broadscale Manta Tows) across the entire extent of the GBR, with higher spatial resolution monitoring at a subset of 47 of these 99 reefs (i.e. video surveys). Coral cover is measured using either video or high-resolution still cameras along replicate fixed transects (see Table 3). The LTMP also surveys reef fish assemblages, again using video, and supplements these finer-scale coral assessments with broader scale surveys (i.e. at the scale of whole reefs) performed using Manta Tows at a larger number of reefs. This enables the LTMP to measure larger-scale changes in coral cover, crown-of-thorns starfish densities and other large-scale disturbances.

Similar high spatial resolution techniques have been utilized by DEC in Western Australia to monitor coral communities in Ningaloo Marine National Park since 1989. One such study has monitored *Drupella* gastropod outbreaks whilst the other has measured the recovery of shallow water coral communities in Bill's Bay, Ningaloo MNP, following a major natural disturbance in 1989 (but see also coral monitoring in Solitary Island MNP). These methods have also been co-opted more recently by AIMS to monitor inshore reef condition at 30 reefs in the GBRWHA. The focus of this project is to link reef health with water quality for these inshore reef communities. Similar methods are used to monitor reef condition in south-eastern Queensland. In general coral reefs are only monitored once a year. It is either impractical or too expensive to monitor more frequently, but this also suggests that seasonal variability is negligible against the long-term trend.

#### 3.3.2 Mangroves

Only three mangrove monitoring projects were listed in this review. Two use aerial photo records to retrospectively examine changes in mangrove extent in NSW estuaries and around Darwin since the 1970s. The other study conducted at Port Curtis, Gladstone, measured structural characteristics of mangrove forests at fixed plots over a 10 year period. In the case of NSW estuary project this comparison only comprises two sets of temporal data (from the 1970s and more recently) leading to some uncertainty about the trend observed (i.e. can you derived a trend from only two data points?). It is debatable whether retrospective projects in isolation provide an insight into the current condition of mangrove habitats, but do provide an important historical basis for future monitoring and restoration.

Table 3. Methods, indicators, spatial coverage, duration and frequency of monitoring for marine benthic habitats

State	Habitat	Project	Methods & Indicators	Spatial coverage	Duration (time-lines)	Frequency
NT	Coral	Monitoring of coral reefs at Cobourg Peninsula	Coral cover measured using fixed 1 m quadrats	4 locations	2001–2006 (discontinued)	1 x per year
Qld	Coral	Long-term GBR monitoring program (GBR LTMP)	Monitoring undertaken at 2 scales: A) Broadscale surveys of reefs using Manta Tows - coral cover, crown-of-thorn pop. density + other large scale disturbances; B) video surveys of benthos and fish assemblages using fixed transects x 5 (see Sweaman et al. 2007 for details)	A) 99 reefs (2005); B) 47 reefs (2005)	A) 1986–ongoing (19 yrs); B) 1993–ongoing (13 yrs)	1 x per year
Qld	Coral	Inshore coral reef demography and assessment	coral cover (fixed transects), sub-adult coral growth and survival, coral settlement/recruitment (settlement plates), chemical composition (C, N) of adjacent reef sediments	30 reefs	2005–ongoing	14 “core reefs” monitored annually, the others every 2 years
Qld	Coral	Ecosystem Health Monitoring Program	video 3 x 20 m fixed transects; measure benthic coral, macroalgae, sessile invert cover	5 sites	2000–ongoing	1 x per year
WA	Coral	Ningaloo Marine Park <i>Drupella</i> long-term monitoring program	Density of <i>Drupella</i> spp., cover of benthic coral reef communities	19 locations, 3 replicate sites per location. 300km coastline	1989–ongoing	every 3 yrs (next survey due in 2008)

WA	Coral	Dampier Archipelago long-term monitoring project	Abundance, size and composition of finfish assemblages with a focus on recreationally targeted species. Cover of benthic reef communities (coral)	35 sites	2007–ongoing	TBD
WA	Coral	Recovery of coral communities in Bill's Bay, Ningaloo Marine Park (1989–2006)	video 3 x 50 m fixed transects; measure benthic coral cover and composition	17 sites	pre/post 1989, 1994, 2000, 2006	
Qld	Mangroves	Port Curits mangrove monitoring program	fixed plots were monitored for productivity, basal area, foliage cover, crab activity, sediment type and sedimentation		1994–2004 (10 years)	1 x year
NT	Mangroves and associated coastal vegetation	Mangrove change in Darwin coastal swamps	changes in cover of mangroves/coastal vegetation using aerial photos	30km <sup>2</sup>	1974–2004	9 intervals within 30 years, giving a temporal resolution of 3 to 4 years
NSW	Seagrass, mangrove and saltmarsh	Broadscale monitoring of seagrass, saltmarsh and mangroves in NSW estuaries	aerial photo assessment of extent (cover) of seagrass, mangrove and saltmarsh	150 estuaries across NSW	2 sets of images 1) late 1970s/early 80s, 2) early 2000s	see duration

Qld	Seagrass	Status of seagrass habitats in GBR World Heritage Area	Multi-faceted/multi-scale approach comprising 1) Broad-scale mapping via diving, surface observation or remote video, 2) Fine-scale assessment and monitoring of key risk areas, 3) Seagrass Watch (community monitoring predominantly at intertidal sites): seagrass cover/composition, epiphyte cover, and 4) modelled seagrass depth limits > 15 m	1) within each NRM region; 2) 40 sites; 3) 61 sites	2) mid 90s (varies b/w sites)-ongoing, 3) 1998-ongoing	2) once a year; 3) 4 times/year
Qld	Seagrass	Ecosystem Health Monitoring Program	seagrass depth range,	15 sites	2000–ongoing	2 x per year
VIC	Seagrass	Victorian multi-regional seagrass assessment	changes in areal extent mapped from aerial photography and direct measurement of seagrass variables at quadrats including seagrass density, length, epiphyte load and seed production	see location, plus 3 sites per Bay	2004–07	twice/year (autumn and spring)
VIC	Seagrass	Seagrass monitoring at Blairgowrie, Port Phillip Bay	changes in cover of seagrass estimated from aerial photos		1957–2005	
WA	Seagrass	Seagrass health monitoring – Perth metropolitan region	shoot height and density, canopy cover	22 locations, plus Jurien Bay (300 km) since 2003	1994–ongoing	1 x year since 1998
SA	Seagrass (subtidal)	Nearshore seagrass change along the Adelaide metropolitan coast	Seagrass coverage as measured using aerial photos	40,000 km <sup>2</sup>	1994–ongoing (historical photos dating back to 1949)	every 5 yrs
SA	Sediments/epifauna	Benthic Protection Zone monitoring project	Biodiversity of epifauna (2002, 2006) and infauna (2006), sediment composition	65 sites, 20 inside BPZ	2002 and 2006	2002, 2006 surveys

NSW	Subtidal subtropical reef/coral	Monitoring of Solitary Islands Marine Park	coral cover measured using 6 x 25 m video transects	16 sites	2002, 2004, 2006 - ongoing	every 2 years (see 3)
NSW	Subtidal temperate reef	Nearshore reef monitoring; northern NSW	benthic community structure (sessile); fish, mollusc and echinoderm diversity; coral cover and health; habitat rugosity; debris load; sedimentation; sea temperature	12 reefs	2005-2008	1 x per year
SA	Subtidal temperate reef	Health of subtidal reef environments in South Australia	Composition and abundance of reef fish species, benthic cover of macroalgae/invertebrates. Presence of invasive species	Initially 14 sites growing to 38 sites by 2005	1996,1999,2005 and 2007	one-off surveys, see duration
Southern Aust	Subtidal temperate reef	MPA ecological monitoring	Composition and abundance of reef fish species, mobile invertebrates. Benthic cover of macroalgae/sessile invertebrates. Presence of invasive species	373 sites at 16 locations across Sthn Aust from Jurien Bay, WA to Lord Howe Is.	Varies. Tasmanian surveys date back to 1992, but interstate project more recent (>2000)	Generally 1 x per year
TAS	Subtidal temperate reef	Condition of Tasmanian rocky reef communities	Composition and abundance of reef fish species, mobile invertebrates. Benthic cover of macroalgae/sessile invertebrates. Presence of invasive species	130 sites (1994), 150 sites (2005/7) around Tasmania	1994, 2006/07	Only 2 surveys completed
VIC	Subtidal temperate reef	Victorian MPA monitoring	Composition and abundance of reef fish species, mobile invertebrates. Benthic cover of macroalgae/sessile invertebrates.	N/A	N/A	N/A

### 3.3.3 Seagrass

There are two broad approaches used to monitor seagrass condition around Australia. The first involves using aerial photo records to estimate change in seagrass cover over time. This has generated information on historical patterns, dating back to the 1950s, for seagrass in Port Phillip Bay, Victoria and the Gulf St Vincent, South Australia and from the 1970s for seagrass in NSW estuaries. The second approach, measures aspects of seagrass condition such as shoot height, density, canopy cover and epiphyte loads at smaller spatial scales. For some projects such as the 'Status of seagrass habitats in GBRWHA' these approaches are powerfully combined.

It is important to note that aerial photos of the coast were not collected for purpose of estimating seagrass extent and hence there may be errors associated with their use. For example, reflection (off the sea) may obscure attempts to delineate subtidal seagrass cover accurately, whereas attempts to measure seagrass extent in deeper waters are inherently difficult and prone to error. As a consequence is often difficult to estimate change for deeper water seagrass habitats. These issues are less problematic for intertidal seagrass (although, there maybe difficulties delineating intertidal habitats particularly where seagrass from saltmarsh coincide). Projects using historical records only document (quite coarse) changes in the extent of habitats, whereas contemporaneous studies operating at a range of scales may provide greater evidence about the causes and drivers of such changes. It would appear that many seagrass beds have stabilized in recent years, but have failed to re-establish into areas where they were historically found. Such historical data is therefore quite valuable to ongoing management of seagrass habitats.

The most comprehensive seagrass monitoring program in Australia is undertaken for seagrass habitats in GBR World Heritage Area by the Queensland Department of Primary Industries. This is a multi-faceted project undertaken at a range of scales covering the coast of Queensland from Cape Yorke to the Burdekin River. It combines broadscale mapping of seagrass habitats with finer-scale assessment of the condition of seagrass meadows in key risk areas at approximately 40 sites (see Table 3). Additional monitoring of principally intertidal seagrass is undertaken by seagrass watch (a community monitoring initiative) at a further 61 sites. Current assessments are based on data dating back to the mid 1990s for the fine-scale monitoring and to 1998 for the 'Seagrass Watch' monitoring. David Ball (Victoria) is also using similar multi-scale approach to assess seagrass habitats in Port Phillip Bay, Western Port Bay and Corner Inlet.

### 3.3.4 Sediments

Little can be said about how soft-sediment habitats are monitored as only a single study was identified in this review. This study examining the exclusion of trawling from deepwater benthic habitats in the Great Australian Bight is so question specific that few generalities can be drawn.

### 3.3.5 Subtidal rocky reefs

In contrast to coral reef-based projects where video surveys are the norm, visual census techniques predominate amongst temperate reef monitoring projects. This is primarily because reduced visibility and water clarity in temperate waters precludes the use of underwater video, particularly for fish surveys. The other major difference between coral and temperate reef monitoring is the use of randomized rather than fixed transects for monitoring subtidal reef communities. On coral reefs, fixed transects are established by placing bolts or other permanent markers into the coral substrate and using these to align transects between surveys. However, this method is impractical on temperate reefs where macroalgal cover often obscures such markers making them almost impossible to relocate between surveys. Placing bolts into rock, particularly granite, is also very difficult underwater.

One of the advantages of using fixed over randomized transects is that such measurements are less prone to small-scale spatial confounding than randomly placed transects. That is researchers may misconstrue temporal for what are actually small-scale spatial differences between sampling events. Such variation, due to small-scale patchiness and spatial heterogeneity, often exceeds temporal variability in benthic systems. It is possible, however, to overcome this problem by incorporating sufficient replication at the scale of the reef. It is not clear whether the studies reviewed here achieve this. The downside of using fixed transects is that they will only detect changes that occur along the transect and obviously not elsewhere on the reef. This might be a problem where impacts are spatially patchy rather than diffuse in nature and needs to be assessed on a case-by-case basis.

Much of the information collected by these studies is likely to be compatible. It includes many of the same indicators, principally fish (composition and abundance) and benthic assemblage (cover) structure, and is collected using similar methodologies. Data is currently available for reefs from subtropical northern NSW to Jurien Bay on the west coast of WA. Significant gaps exist for the central coast of NSW and from Port Lincoln to south-western WA, although the latter is a remote and difficult region to access. As discussed above, much of the monitoring of subtidal reefs coincides with the recent proclamation of MPAs and this is particularly the case in NSW, Victoria, Western Australia and was one of the initial rationales in Tasmania. The most comprehensive monitoring program undertaken in southern Australia is that lead by Graham Edgar, University of Tasmania, looking at the ecological impact of MPAs. This project comprises 373 sites at 16 locations across southern Australia, although the temporal coverage of data varies between locations. Other comprehensive surveys of reef condition include the Tasmania wide survey undertaken by Neville Barrett and the Reef Health project undertaken by SARDI to assess the condition of metropolitan Adelaide reefs (see Table 3).

### 3.4 How are assessments made?

This section addresses on what logical basis assessments are made. Such a question is directly related to the initial aims of the monitoring project and consequently the way in which data was collected (i.e. the sampling design utilised). It is important to note that not all projects reviewed here were set up explicitly to monitor human impacts or provide information on the condition of habitats. For example, the GBR LTMP was initially set up to monitor outbreaks of the crown-of-thorns starfish, which appeared so devastating in the

1980s, whereas the earliest attempts to map and assess seagrass cover in Queensland were undertaken as part of fisheries assessments by DPI in the 1980s. These studies have subsequently morphed into long-term and broad geographic assessments of coral and seagrass.

The most common method of assessment reported was via trend analysis (Table 4). In some cases this is quite sophisticated (i.e. use of Generalised Linear Modelling (GLM) techniques to model temporal trends in LTMP and Darwin Coastal mangrove data), but often it is not. In the case of the GBR LTMP and the status of seagrass in the GBRWHA these assessments can be made from region-to-region and from site-to-site. However, for this analysis to be meaningful, projects must have a reasonable amount of temporal data from which to draw rigorous conclusions. In the absence of other assessment frameworks (see below) only a handful of studies presently have sufficient data to report convincingly on current trends.

Few studies explicitly incorporate reference sites or regions, presumably because such areas are difficult to locate for a range of areas of interest. In the case of the 'ecosystem health monitoring program' (in south-eastern Queensland) the Noosa River is used as a reference system for water quality objectives, however, there are no comparable systems for seagrass and coral habitats in the region. The project proponents therefore have no option, but to use trend analysis to assess the condition of these habitats.

More generally, reference points are difficult to identify because of the issue of sliding baselines (Dayton et al. 1998). Choosing reference sites is problematic because few regions (particularly close to human population centres) are completely unaffected by human impacts. While some propose that desirable conditions should be set to pre-European settlement levels, others argue the presence of humans cannot be denied and suggest more realistic target conditions for ecosystem health. Inevitably, this means compromises must be made.

Identifying reference points is much simpler in the case of MPA studies where the object of monitoring has been to examine the impact of (generally) reducing fishing in protected regions. The appropriate reference points for these studies are therefore comparable sites located outside the protected area. If the exclusion of fishing has an impact on reef ecosystems then unfished areas should over time become increasingly distinguishable from fished areas in ways which are consistent with the exclusion of fishing in the area. Such studies were designed with the explicit purpose of assessing how well marine protected areas function, particularly in relation to the protection they provide for different aspects of reef biodiversity, but also MPA size and configuration. These studies are also likely to provide information on how fishing (both recreational and commercial) impacts inshore reef ecosystems. However, and this is an important point, such studies do not convey broad geographic information on the status of subtidal temperate reefs, despite the wide coverage of these studies because they were simply not designed to make such assessments.

Table 4. Assessment basis for monitoring projects included in this review.

State	Habitat	Project	Impacts	Assessment basis
NT	Coral	Monitoring of coral reefs at Cobourg Peninsula	Shallow reefs are susceptible to thermal stress and consequently bleaching (via climate change)	Study investigated whether coral bleaching events could be detected using standard monitoring techniques and whether these events could be linked to satellite generated SWT
Qld	Coral	Long-term GBR monitoring program (GBR LTMP)	Human visitation, fishing, climate change, crown-of-thorn starfish outbreaks (possibly linked to human activities)	Trend analysis using GLM mixed effects models
Qld	Coral	Inshore coral reef demography and assessment	Diffuse land run-off, input of nutrients and sediments from agricultural activity in the catchments adjacent to the GBR	Spatial analysis matching coral reef status with water quality data
Qld	Coral	Ecosystem Health Monitoring Program (SE Queensland)	Diffuse land run-off, input of nutrients and sediments from agricultural activity and urban development	Trend analysis - no clear reference sites for coral
WA	Coral	Ningaloo Marine Park <i>Drupella</i> long-term monitoring program	<i>Drupella</i> (a corallivorous gastropod) populations may be influenced by fishing pressure	Trend analysis
WA	Coral	Dampier Archipelago long-term monitoring project	Recreational fishing; oil and gas industry activities and infrastructure development	No assessment has been undertaken to date

WA	Coral	Recovery of coral communities in Bill's Bay, Ningaloo Marine Park (1989-2006)	Study follows recovery of corals in shallow bay in response to a natural anoxic event resulting in a 100% mortality event (1989)	Trend analysis comparing coral recovery against unimpacted coral communities in deeper waters
Qld	Mangroves	Port Currits Mangrove Monitoring Programme	Reclamation of adjacent tidal wetland areas	
NT	Mangroves and associated coastal vegetation	Mangrove change in Darwin Coastal Swamps	Effluent from sewage treatment plant and drainage (as part of Mosquito control)	Trend analysis using GLM
NSW	Seagrass, mangrove and saltmarsh	Broadscale monitoring of seagrass, saltmarsh and mangroves in NSW estuaries	Land use changes (elevated inputs of nutrients/sediments), changes to river flows and hydrology, dredging and land reclamation	Limited trend assessment possible between 70/80s and 2000s . NB. Only 2 data points in time!
Qld	Seagrass	Status of seagrass habitats in GBR World Heritage Area	Increased sediment/nutrient loads (agriculture), Pesticides, Coastal development and climate change (future)	Trend analysis comparing sites and regions
Qld	Seagrass	Ecosystem Health Monitoring Program	Diffuse elevated inputs of nutrients/sediments linked to rapid urban development	Trend analysis - no clear reference sites for seagrass
VIC	Seagrass	Victorian Multi-regional Seagrass Assessment	Diffuse elevated inputs of nutrients/sediments from urban and agricultural areas	Trend analysis relative to baseline mapping in 1998 and 2000
VIC	Seagrass	Seagrass monitoring at Blairgowrie, Port Phillip Bay	Catchment runoff from urbanised areas (nutrients/sediments), localised damage from boat anchorage	Trend analysis
WA	Seagrass	Seagrass health monitoring – Perth metropolitan region	Nutrient enrichment and elevated suspended solids in the nearshore environment	Trend analysis
SA	Seagrass	Metropolitan Adelaide seagrass study	Nutrient enrichment and elevated suspended solids in the nearshore environment	Trend analysis

SA	Sediments/ epifauna	Benthic Protection Zone monitoring project	Demersal trawling is prohibited within the BPZ due to potential impacts on benthic communities thus providing an insight into impacts of trawling for sites outside this zone	Condition of sites outside BPZ assessed relative to those within
NSW	Subtidal subtropical reef/coral	Monitoring of Solitary Islands Marine Park	Human visitation, fishing, climate change, subtropical white syndrome coral disease	No assessment has been undertaken to date
NSW	Subtidal temperate reef	Nearshore reef monitoring; Nthn NSW	Rapid urban development: marine debris, sedimentation and urban run-off (nutrients)	Combination of reference sites (in marine parks or areas with low population density) and trend analysis
SA	Subtidal temperate reef	Health of subtidal reef environments in South Australia	Reefs closest to metropolitan Adelaide impacted by increased nutrients (wastewater and stormwater), sedimentation and turbidity. Fishing may also exert an influence.	Reference approach comparing metropolitan with non-metropolitan reefs
Southern Aust	Subtidal temperate reef	MPA ecological monitoring	Fishing (recreational and commercial), introduced species, climate change	Changes in MPAs measured relative to adjacent control sites over time
TAS	Subtidal temperate reef	Condition of Tasmanian rocky reef communities	Fishing (recreational and commercial), introduced species, climate change	Some limited trend analysis between 1994 and 2006/7 surveys
VIC	Subtidal temperate reef	Victorian MPA monitoring		No assessment has been undertaken to date

A better example of where a reference approach has been used to examine the health of a habitat is that employed by the reef health project in South Australia. This project compared the condition of putatively impacted reefs off the coast of metropolitan Adelaide with reefs south of Adelaide on four separate occasions. One flaw with this approach is that it is impossible to establish whether the reefs south of Adelaide resembled those off the coast of Adelaide prior to the impact (in this case urbanization) because of a lack of knowledge about the prior state of these reefs. Thus, it is impossible to state with certainty whether the southern reefs represent appropriate reference points. This highlights two common problems that face almost all monitoring projects: 1) insufficient information about the condition of habitats prior to the onset of human impacts, and 2) difficulty in identifying appropriate reference sites/areas. Many human impacts of concern have a long-standing history (particularly nutrient and sediment inputs) and, in fact, may have been worse in the past – this is particularly true for sewage inputs due to improvements in the treatment and processing of sewage in recent decades. Inevitably this forces monitoring projects to adopt a range of compromises and make a number of assumptions that temper the outcomes of the monitoring assessments. In most cases these are unavoidable, but should be clearly articulated when conveying the outcome of such habitat assessments.

### **3.5 Assessment outcomes**

#### **3.5.1 Coral reefs**

Despite the wide coverage of coral reef monitoring across northern Australia, useful information about the status of coral reef ecosystems can only be garnered from a single monitoring program – the GBR LTMP. Monitoring of inshore coral reef systems in the GBR World Heritage Area (also undertaken by AIMS) is in its early days, whereas many of the West Australian coral reef monitoring projects appear limited in scope, falling within the realm of compliance monitoring. This situation is likely to improve, as current projects develop greater focus and longer time-lines allow more robust assessments to be made. A number of other monitoring projects are also about to come online, particularly in north-west WA where offshore oil and gas exploration and extraction has necessitated the development of monitor programs in an attempt to manage these offshore ecosystems.

In general, the health of the GBR is excellent, crown-of-thorns starfish outbreaks are down relative to past records, as is the incidence of coral disease. With the odd exception (e.g. Innisfail sector) coral cover is stable across the entire GBR and has even increased, along with fish numbers, relative to 1989 lows in the southern Capricorn Bunker Group. For a more detailed overview see Sweatman et al. (2005). In Bill's Bay in the Ningaloo Marine National Park coral communities have recovered to pre-1989 levels following a natural anoxic event in which almost all of the coral was killed. This suggests that coral reefs in this reasonably remote part of the Australian coastline are in good health.

Table 5. Reported outcomes for benthic habitat assessments

State	Habitat	Project	Freq. assessment	Assessment outcomes
NT	Coral	Monitoring of coral reefs at Cobourg Peninsula	N/A	Methods-based project
Qld	Coral	Long-term GBR monitoring program (GBR LTMP)	Status report published every second year	Crown-of-thorns starfish outbreaks + incidence of coral disease lower than past; coral cover stable, although some localised declines detected (e.g. Innisfail sector - associated with starfish outbreaks and high coral bleaching)
Qld	Coral	Inshore coral reef demography and assessment	Annual report to GBRMPA	Too early for any useful trend analysis
Qld	Coral	Ecosystem Health Monitoring Program	EHMP report card is released in October every year	General overall improvement in ecosystem health in 2006/07 due to low rainfall and associated runoff, but not clear how assessments made for coral communities
WA	Coral	Ningaloo Marine Park <i>Drupella</i> long-term monitoring program	every three years, (at least one report and one management guideline are produced after each survey)	Compliance monitoring principally characterizing MPA biodiversity and establishing baseline data
WA	Coral	Dampier Archipelago long-term monitoring project	coinciding with each survey	2007 survey data - yet to be analysed
WA	Coral	Recovery of coral communities in Bill's Bay, Ningaloo Marine Park (1989-2006)	every 5–6 years	By 2006 coral cover exceeds pre-impact levels and is similar to coral cover on outer reefs

Qld	Mangroves	Port Curits mangrove monitoring program	One-off assessment	Mangrove communities monitored in Port Curtis changed with season and possibly in response to natural environmental influences. However, no evidence that adjacent land reclamation activities have impacted on the health of the mangroves.
NT	Mangroves and associated coastal vegetation	Mangrove change in Darwin coastal swamps	Ongoing research project	Study measured an increase in total mangrove area over the 30 yr period, with more mangrove forest in total area now than existed pre- Cyclone Tracy. This is due to an expansion inland, with mangroves invading areas that were previously brackish reed swamps, and an expansion of mangroves at increasing distances from the tidal creeks.
NSW	Seagrass, mangrove and saltmarsh	Broadscale monitoring of seagrass, saltmarsh and mangroves in NSW estuaries	2 reports published	With caveats (relative to the 1970s) large gain in saltmarsh (due largely to enhanced resolution and discovery of new patches), large net gain in mangroves (due to expansion) and a small net gain in seagrass
Qld	Seagrass	Seagrass habitats in GBR World Heritage Area	Periodic reports prepared for different regions	Healthy state. Seagrass cover has remained relatively stable over the past 20 years, with periodic fluctuations in response to localised disturbances or acute events (e.g. cyclones). Small losses recorded in Townsville and Airlie Beach areas linked with coastal development.
Qld	Seagrass	Ecosystem Health Monitoring Program	EHMP Report Card is released in October every year	General overall improvement in ecosystem health in 2006/07 due to low rainfall and associated run-off, but not clear how assessments made for seagrass

VIC	Seagrass	Victorian multi-regional seagrass assessment	Single assessment completed at the end of project	Recorded large declines in seagrass area at sites in Port Phillip Bay and Corner Inlet since the last baseline mapping in 1998 and 2000 respectively, while seagrass in Western Port had remained relatively stable.
VIC	Seagrass	Seagrass monitoring at Blairgowrie, Port Phillip Bay	N/A	Increase in cover 1950-2000, followed by significant decline since
WA	Seagrass	Seagrass health monitoring – Perth metropolitan region	Annual reports to EPA and Cockburn Sound Management Council	Almost 80% of seagrasses have been lost in Cockburn Sound. Monitoring has led to the development and refinement of Environmental Quality Criteria, to monitor and respond to changes in seagrass health.
SA	Seagrass		every 3 years	Estimated 5000 ha lost in Adelaide metropolitan region since 1940s. Further 720 ha lost since 1996.
SA	Sediments/ epifauna	Benthic Protection Zone monitoring project	N/A	BPZ is well placed to represent the benthic biodiversity of the eastern and central GAB, but no formal assessments of trawling impacts have yet been completed.
NSW	Subtidal subtropical reef/coral	Monitoring of Solitary Islands Marine Park	N/A	Compliance monitoring principally characterizing MPA biodiversity and establishing baseline data
NSW	Subtidal temperate reef	Nearshore reef monitoring; northern NSW	Annually	Too early for any useful analysis; work used to establish methods

SA	Subtidal temperate reef	Health of subtidal reef environments in South Australia	Reports in 1998, 2000, 2007	Northern metropolitan reefs (adjacent to Adelaide) appear to be in poor condition, with red foliaceous and turfing macroalgae dominating relative to southern and non-metro reefs
Southern Aust	Subtidal temperate reef	MPA ecological monitoring	Irregular; Tasmanian but not interstate findings published	Response of reef communities to protection from fishing varies greatly between MPAs, depending on a variety of factors, most importantly MPA size, magnitude of fishing pressure prior to protection, extent of compliance, heterogeneity of reef surfaces, and time since fishing was controlled. For Tasmanian MPAs, rock lobsters and large fish species typically show rapid (<5 years) response to protection in large MPAs, but with little ecological change associated with protection in small (1 km span or less) MPAs.
TAS	Subtidal temperate reef	Condition of Tasmanian rocky reef communities	Irregular	Despite considerable pressures on Tasmanian reefs in the form of ocean warming, fishing, introduced species and pollution, little overall change was evident between the early 1990s and 2006/2007. However, substantial changes were observed in several species, notably a decrease in biomass of exploited finfishes >30 cm, and an increase in the abundance of the barren-forming, long-spined sea urchin <i>Centrostephanus rodgersii</i> .
VIC	Subtidal temperate reef	Victorian MPA monitoring	N/A	Compliance monitoring principally characterizing MPA biodiversity and establishing baseline data

### 3.5.2 Mangroves

Little can be learnt from the Port Curtis Mangrove Study as it is so limited in scope. Its inclusion in this review probably represents a lax application of the selection criteria outlined in aims and illustrates clearly why such projects were excluded. Perhaps if there were more such studies we might be in a stronger position to understand the impact of land-use changes on mangrove communities. It is possible that there are a range of similar studies completed by consultants, government – perhaps some sort of meta-analysis is in order. The other two studies examining historical changes in the extent of mangrove forests in NSW estuaries and in Darwin coastal swamps both indicate that there have been major gains in mangrove forest cover relative to 1970s levels. The lack of such information for the coast of Queensland appears to be an obvious omission.

### 3.5.3 Seagrass

Seagrasses are found in all Australian waters. However, the species composition of these communities varies considerably between tropic and temperate regions. Upon reviewing the outcomes of the seagrass monitoring projects included in this review one is left with the impression that temperate seagrass communities are more degraded than their tropical counterparts. This is particularly true of seagrasses found in close proximity to southern population centres, such as Adelaide, Perth and Melbourne where substantial seagrass losses have been recorded. Recent assessments indicate that this is not just an historical artifact (although the greatest losses are historical), but an ongoing problem. The Adelaide coastline has lost a further 720 ha of seagrass since 1996 on top of what are historically high seagrass losses (see Table 5). In Victoria recent assessments have measured large declines in seagrass cover in Port Phillip Bay and Corner Inlet since the last baseline mapping in 1998–2000. This pattern is also reflected in long-term aerial photo records for seagrass cover at Blairgowrie, in the southern part of Port Phillip Bay. These records display a pattern of substantial recovery since historical lows in the 1950s, followed by a significant decline since 2000. It is not clear whether this is a natural pattern.

Similarly high levels of seagrass loss have also been recorded for Western Cove, Kangaroo Island and Rivoli Bay on the south-east coast of South Australia, although there is little ongoing monitoring of these regions. Historically, seagrass loss has been linked to elevated nutrient and sediment loads; although accelerated erosion and fragmentation has led to continuing losses despite improvements in nearshore water quality in the Adelaide Metropolitan region (see Westphalen et al. 2005).

By comparison, seagrass habitats in the GBR World Heritage Area appear to be in good health (Coles et al. 2007). Seagrass cover has remained relatively stable over the past 20 years, despite periodic fluctuations in response to localized disturbances (e.g. cyclones). Small losses (approx. 20 ha) have been recorded in the Townsville and Airlie Beach regions due to coastal development. This situation is quite remarkable given there are significant pressures acting on seagrass habitats in this region. Queensland rivers, for example, deliver nutrient and sediment loads into nearshore coastal waters that far exceed pre-European levels, yet tropical seagrass meadows appear to be in better health than their temperate counterparts. Further south, seagrass meadows in Moreton Bay have become severely degraded adjacent to the city of Brisbane, but appear in good health elsewhere in

south-east Queensland (see Ecosystem Health Monitoring Program). Broad-scale mapping of intertidal seagrass beds in NSW estuaries also recorded, overall, small net gains in seagrass coverage relative to 1970s levels.

#### 3.5.4 Sediments

Virtually nothing is known about the current status of soft-sediment habitats around Australia.

#### 3.5.5 Temperate reefs

Monitoring of temperate subtidal reefs is widespread throughout southern Australia. However, one major drawback to deriving broad-scale assessments of temperate reef condition is that most reef monitoring is not undertaken to assess reef health/condition per se, but to assess how well MPAs perform. Indirectly, this may provide information about the extent to which fishing impacts on reef ecosystems, but will provide only limited information on the health of temperate reefs. In part, this is because MPAs principally provide protection from fishing, whereas they provide only limited protection from other, more diffuse, impacts such as pollution. As a consequence MPAs may not always be ideal reference points for determining human impacts on reefs (i.e. this needs to be assessed independently). In addition, the extent to which MPAs represent unfished conditions is clearly dependent on the duration of protection. As most MPAs were formerly fished, it may take > 10 years for fish populations to recover from the effects of fishing (Edgar and Barrett 1999). Many MPAs particularly in Western Australia, South Australia and Victoria have only recently been enacted and some smaller MPAs may not adequately protect reef biodiversity (regardless of how long they are protected). The primary aim of such projects is provide information on how to select, design and implement marine parks (although in this regard the findings are largely restricted to temperate reef habitats).

Nonetheless, proponents of MPA monitoring argue that these projects will over time help to detect and measure future and ongoing impacts such as climate change (Graham Edgar pers. com.). A similar argument can also be made for other ongoing long-term monitoring projects. This is because the form and extent of such changes can only be assessed through systematic long-term data collection. The value of such data sources can be clearly illustrated by the oceanographic changes observed off the east coast of Tasmania over the past 50 years. Over this time sea surface temperatures off the east coast of Tasmania have warmed significantly due in part to an increase in the strength of the East Australian Current and a relative contraction in the intrusion of cooler and nutrient rich southern waters. Using a series of fragmented data sets, collected for often disparate purposes, researchers have built a picture of ecological change along this coastline. This includes a shift in the composition of zoo- and phytoplankton communities in nearshore waters, a contraction in the range of the giant kelp *Macrocystis pyrifera* from the east to the south-east coast and the southern range expansion of the sea urchin *Centrostephanus rodgersi* from the Australian mainland to the east coast of Tasmania. However, changes to other ecological components have probably gone unnoticed/recorded due to insufficient information and there remain a number of gaps in terms of the rate and extent of past changes (e.g. particularly for kelp). The need to commit to long-term data collection in the marine environment cannot be overstated.

As is the case for coral reefs, other monitoring falls within the realm of compliance monitoring. This is particularly the case for the Victorian Subtidal Reef Monitoring and solitary Island Marine park monitoring programs where both programs are in their earliest days of inception. The primary focus of these monitoring programs is to characterize and catalogue assets (i.e. reef biodiversity) and provide data to inform future management of reef environments in accordance with the management criteria laid out in each park's management plan. Whilst important aims for newly established marine parks, such programs do not necessarily provide detailed information on the condition of reefs, particularly where there is insufficient data about past trends. Where reefs are obviously degraded, resulting in the wholesale loss of brown macroalgal cover (e.g. metropolitan Adelaide reefs), such monitoring programs may be sufficient to determine condition. In Victoria there appears to be no overall synthesis of reef monitoring efforts to date.

The South Australian Reef Health program conducted in Gulf St Vincent appears to be one of the few studies where deterioration in reef condition has been demonstrated (although see caveats above). The condition of metropolitan Adelaide reefs was determined to be poor, with red and turfing algae dominating, relative to non-metro and southern reefs where robust brown macroalgae dominate. Poor water quality has again been implicated and these changes are consistent with massive losses of seagrass recorded along this coastline.

## 4. Summary

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There are substantial gaps in monitoring across Australia both in terms of habitat and geographic coverage. Whilst there is a preponderance of reef monitoring (both coral and temperate rocky), a range of other benthic habitat types are under-represented. Specifically, there appears to be little monitoring of soft-sediment habitats such as mud flats, sandy/muddy bays and beaches. There is also little formal monitoring of vulnerable (to climatic change) intertidal habitats such as mangroves, saltmarsh and intertidal rocky reefs. This is surprising given that these habitats are the focus of other research conducted in coastal environments, largely due to their ease of accessibility. Moreover, where benthic habitats are monitored geographic coverage may be limited in extent. For example, whilst there is comprehensive monitoring of seagrass condition in proximity to southern population centres little monitoring is conducted along less populated coastlines. Queensland is the only state where there is comprehensive coverage of two habitat types: seagrass and coral reefs (more so since the inclusion of inshore reefs). Both combine broader scale mapping with finer scale monitoring allowing change to be measured at a range of scales. This is important because different impacts manifest at varying scales.

This review has also highlighted some logical difficulties in producing rigorous condition assessments due to deficiencies in design or insufficient temporal data sets. Many current monitoring programs are currently not designed to assess the condition of benthic habitats, but to monitor outbreaks of destructive species (e.g. *Drupella* sp.), collect compliance data such as species inventories and baseline information and assess the performance of MPAs. This further diminishes attempts to derive broadscale ecological condition assessments. Other difficulties arise where methods are compatible, but the data upon which assessments are based, are not. For example, assessments made by the GBR LTMP will be more robust than those made for inshore GRB reefs, despite the use of similar methodologies, simply because the former are based on >15 years data compared to <5 years. This may also be a problem for projects which construct historical trends and past patterns using aerial photo records to measure change in habitat extent over time. Where historical patterns are inferred from only a small number of data points, caution should be exercised when interpreting such patterns. However, such information does provide an important context for current monitoring efforts, particularly where there is an emphasis on the recovery of degraded habitats (e.g. seagrass). Remote sensing methods are, however, only suitable for measuring change in the extent of habitats and are clearly of limited value when attempting to determine the past/or current condition of habitat types that do not change in extent (e.g. reefs). These methods also have limited value in deeper and turbid waters.

Broadscale regional assessments are currently possible for coral reefs and seagrasses within the Great Barrier Reef World Heritage Area, Queensland (although see comments above regarding the varying quality of this data). There is also good information on seagrass condition close to Adelaide, Perth, Melbourne and Brisbane. However, very different methods are used to monitor seagrasses in each of these regions. In contrast, similar methodologies are used to monitor subtidal temperate reef habitats across southern Australia. There is excellent monitoring coverage of Tasmanian subtidal reefs with a range of other locations, generally coinciding with MPAs, spread across southern Australia. However, this information is currently not used to assess reef condition *per se*, but to test the performance of MPAs. In the long-term this program has the capacity to provide

similar information about the status of reefs as the GBR LTMP. Information about the status of other regions and habitats across Australia is severely lacking.

Overall, these monitoring programs relay a good story about the health of Australian marine benthic habitats (see Table 5). Seagrass and coral cover has been stable in the GBRWHA for the past ~ 15 years, although it is too early to make assessments about the condition of inshore reefs where greater degradation may be expected. Elsewhere seagrass declines appear to have stabilized relative to historical trends, commensurate with improvements in nearshore water quality. However, recolonisation of denuded areas is slow. There also appear to be some recent losses in Victoria; however, it is unclear whether this is a natural pattern. In general temperate reefs appear to be in good health throughout southern Australia. Where protection is provided fished species recover quickly and only a small number of reefs, off the metropolitan coast of Adelaide, have actually been found to be significantly degraded. Where information exists for mangroves, populations appear to be stable and have even increased in extent relative to lows in the 1970s.

However, caution should be exercised when attempting to extrapolate such broad assessments to the health of marine benthic environments more generally because of the significant number of gaps in geographic and habitat coverage that exist. To overcome this hurdle will require an increased investment in monitoring, particularly for intertidal habitats, better co-ordination of existing projects and greater focus on designing or re-designing (where possible) studies so that habitat condition can be explicitly assessed.

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