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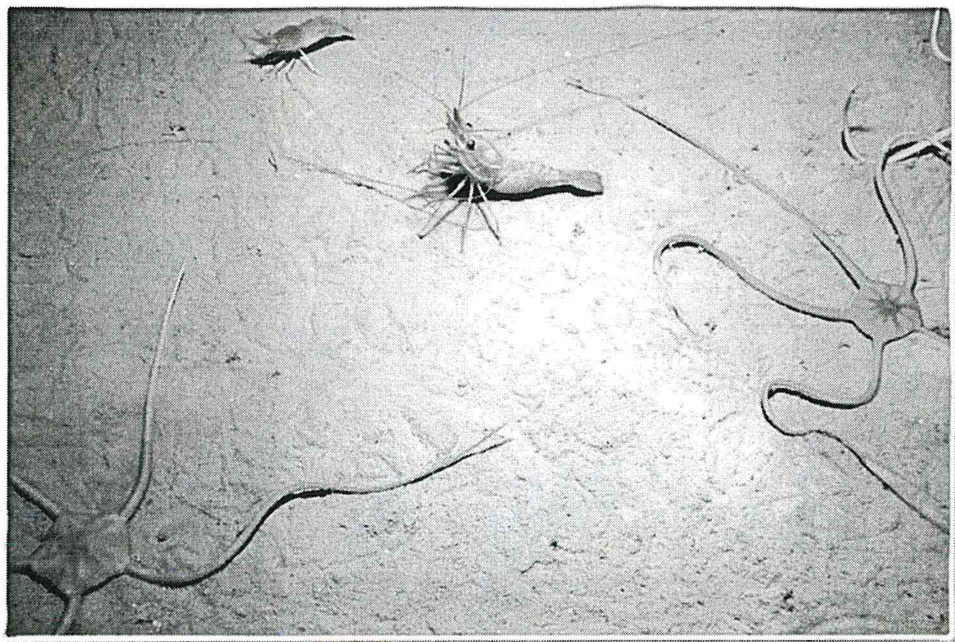

Draft - Commonwealth Tropical Marine Protected Areas Research and Monitoring Strategy

A report prepared for the Department of the Environment and Heritage

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Introduction

The Commonwealth is developing a national strategy for marine research and monitoring activities that will support management and reporting requirements for marine protected areas (Oxley and Heyward 2005). The initial approach, in the development of an overarching national strategy, has been to group the declared MPAs into tropical, temperate and sub-Antarctic bioregions. For each category more specific research and monitoring plans are being developed. This document outlines a strategy for implementation of a coordinated research and monitoring program for the six shallow reef Commonwealth Marine Protected Areas situated in tropical and sub-tropical environments and managed under the EPBC Act 1999;

- Ashmore Reef National Nature Reserve;
- Mermaid Reef Marine National Nature Reserve;
- Cartier Island Marine Reserve;
- Coringa-Herald National Nature Reserve;
- Lihou Reef National Nature Reserve; and
- Elizabeth and Middleton Reefs Marine National Nature Reserve.

All these reserves are listed as IUCN category Ia - strict nature reserve. Such reserves are managed primarily to ensure habitats, ecosystems and native species are preserved in an undisturbed state and to facilitate research. Coral reef ecosystems are common to these reserves and this implementation strategy focuses research and monitoring in the emergent coral reef and shallow water habitats, where methods are well established and a significant range of conservations values and ecological indicators are readily apparent. It should be noted that a broader range of depths, habitats and biodiversity values are associated with these coral reef areas and that the implementation strategy will evolve as the level of knowledge for each MPA increases. For example, an additional Commonwealth tropical MPA exists at Ningaloo Reef in Western Australia that is exclusively a deep water environment, covering waters of the continental shelf and upper continental slope. Although essentially providing a buffer zone to the adjacent coral reef MPA in State waters, this tropical deeper water Commonwealth MPA may have significant biodiversity values in its own right associated with, for example, unique sponge communities along the shelf break. The methods and ecological indicators associated with deeper water habitats are evolving and implementation in the tropics will parallel approaches to research and monitoring strategies below diving depths in all the MPA bioregions.

SCOPE OF STRATEGY

DEH already runs a monitoring program within some of the tropical reserves targeted at seabird species, green turtles, vegetation and marine debris. This report specifically considers a research and monitoring program for the coral reef associated marine flora and fauna with a focus on the coral reef benthos and associated reef fishes, within normal scientific diving depth ranges (0-20m typical, 30m maximum).

Each of the Reserves has slightly different objectives outlined in their management plans (see Appendix 1). The common objective outlined above for each of the MPAs is to ensure protection of the habitats and biodiversity within the parks in as "undisturbed" state as possible. Reference is made to sustaining the 'long term ecological viability" of the systems. Specific research tasks, focussed on unique declared values for each MPA, for example the abundance and diversity of threatened fisheries stocks, are addressed.

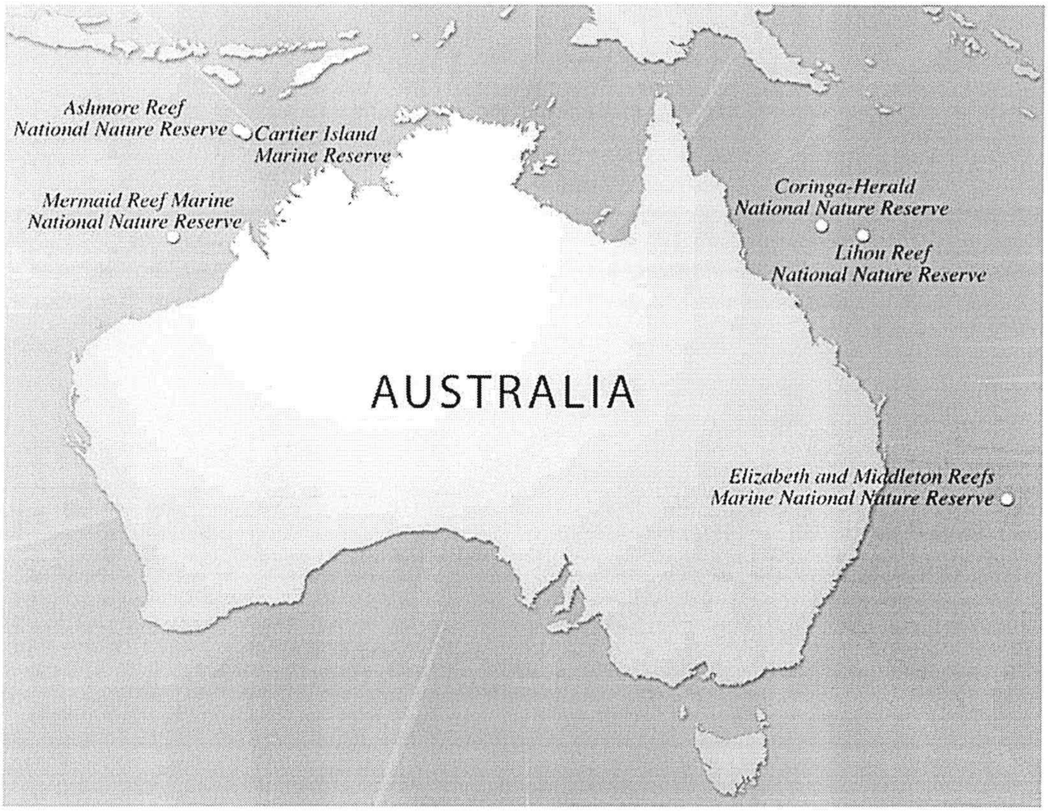

FIGURE 1. Six Commonwealth coral reef reserves managed under the EPBC Act.

Questions to be Addressed by Research and Monitoring

The tropical Commonwealth Reserves are all IUCN Type 1 MPAs, nominally being close to pristine, with natural environmental conditions and little or no environmental modification related to human pressures. While some of these reserves are closer to this model than others, research and monitoring in these reserves should allow measurement of how well this status is being maintained. To that end, a strategic program of research that parallels that proposed in Australia's Antarctic Science Program Science Strategy (http://www.aad.gov.au) is relevant. In particular, research in the tropical reserves should lead to improved understanding of ecosystem structure and characterisation of natural and anthropogenic variability in the key biodiversity values for each MPA.

We know from studies on the Great Barrier Reef (GBR) that on tropical reefs the abundance of stony corals, expressed as percent live coral cover, can vary from 70% to 5% cover then back to 60% cover in 10 years (AIMS 2004). This means that a snap shot observation can be very misleading and consequently short term studies provide a poor view of the state of an ecosystem. It is only when data are collected over longer periods of time that this 'variability' can be identified and quantified. Once an understanding of this is gained, then it is possible to look at trends rather than snapshots and to determine when the system falls outside 'normal bounds' or shows signs of failing to recover. It may also then be possible to tease out the effects of direct human impacts from larger scale climatic events, such as cyclones or increased SST.

At present most of the Commonwealth coral reef reserves have been surveyed on only one or perhaps two occasions over the last 20 years and clearly there is insufficient evidence to provide a comprehensive assessment on their 'health'. However, many of the anthropogenic pressures believed to be responsible for the deterioration of coral reefs globally (http://www.gcrmn.org/Status2004.asp) are currently absent from the Commonwealth reserves, due to there remoteness, and hence it could be implied that the reefs are in relatively good condition. Nonetheless, even the most remote reefs remain vulnerable regional scale disturbances, such as coral bleaching or coral disease, both of which are increasing in significance globally.

The questions that should therefore be asked are suggested as follows:

- What is the state of knowledge of the biodiversity in the MPA and does it include robust measures of abundance and diversity?
- What are the most significant taxa in each of the marine parks form a conservation of biodiversity perspective?

- What are the major drivers of disturbance (threats) to each of the reserves and what data are available on these threats? What do these data show?
- What is the preliminary assessment of the status of each reserve?
- What is the overall picture of the coral reef reserves and how do they compare with Australia's other isolated coral reef areas?
- What habitats are present / distribution?

Experience with Australian coral reefs, using protocols adopted by AIMS long term monitoring project, shows that annual repeated surveys are capable of tracking major changes in abundance and diversity and have revealed cycles of natural major disturbance and recovery occurring over decadal time scales. However, this type of trend data analysis has relied on measures of abundance (percent cover) that may need to be augmented by data on size structure and recruitment to provide more useful indicators of the future trajectory for populations of dominant benthos. While there is a need for several years of trend data in order to begin characterising natural variability, the addition of demographic data on representative species, including some measure of recruitment either directly or via inference from age structure data, is complimentary and may provide more useful short term data related to management performance.

There should also be a focus on monitoring pressures, such as fishing activity, and collecting or securing access to meteorological and oceanographic (metocean) data to test for correlations between the biological data over time. For example sea surface temperature (SST) data are invaluable in providing evidence of bleaching events and wind speed and direction data provide useful information on cyclone activity. These data can provide strong evidence for the impact of both coral bleaching and cyclone/storm activity on coral reef communities. As appropriate algorithms come on stream, a variety of new remote sensing products, such as measures of productivity, salinity and light, will provide broad scale data relevant to ecosystem processes in all the Reserves. In a strategic sense, the integration of the Reserves into a national ocean observing system, where the reserves become reference sites for ground truthing and possibly deployment of metocean instrumentation, may facilitate this linking of physical and biological data.

Priority should be given to collection of information on indicators which may be able to provide warnings of future changes e.g. demography (recruitment, growth, mortality) data can be extremely helpful in hindcasting and forecasting on coral reefs. In most cases the frequency of access to the Commonwealth MPAs will be annual at best, so measure of recruitment will rely on inference, based on an understanding or organism growth.

Research and Monitoring Access to MPAs

All six coral reef reserves are isolated from the Australian mainland and only accessible using a substantial vessel. To date, the majority of access has been achieved with the support of the Australians Customs Service. DEH contractors and Australian government agencies task customs vessels to undertake research and monitoring, with the caveat that Customs operations have priority. This means the vessels may have to be redeployed away from the intended operations during a tasking. Customs currently have 8 Bay Class vessels (38m LOA). These vessels have the capacity to take a dive team of four persons. There are no diving facilities on board the vessels so all equipment must be brought onboard including a dive compressor (3 phase power available), tanks and dive gear. Medical oxygen is limited and so sufficient quantities need to be provided by the dive team. Two tenders are available. The tenders were not designed for diving and provided limited space for gear and kitting up, however they are very good sea-boats and when crewed by two customs staff, provide reasonable surface support for diving.

Individual Customs vessels are able to support a field trip of 7-10 days. At the time of writing there was no charge for use of the customs vessels by Commonwealth agencies and this is a significant cost saving with comparable charter vessels. The Bureau of Meteorology and the Department of Transport conduct routine maintenance of automatic weather stations and maritime lights at some of the Reserves and short term access for retrieving and deploying temperature loggers may be possible.

Research vessels visit the Reserves for specific research projects under permit though this is a relatively rare event. Tourist vessels are also able to visit the Reserves under permit and in some reserves, do so regularly. The public in privately owned vessels also visit the Reserves on a regular basis where they engage in a range of activities including snorkelling and SCUBA diving although this form of visitation is not intense.

Basic Sampling Design Outline

BACKGROUND

Information is required for performance assessment at two spatial scales for the coral reef reserves, the ecosystem level and the reserve level (ANZECC 1999). Whilst there is also interest in understanding how things vary within the Reserves, limited funding and access necessarily restricts the level of sampling possible.

The isolation of all of the coral reef reserves present several difficulties for a sampling. The first challenge is that the Customs vessels, which have provided opportunities for significantly improved access during the last decade, have a maximum residence time in the reserves of about 7-10 days. Furthermore, the border protection priorities of the Customs fleet create uncertainties about access at a specific time, particularly to northern and north-western locations. Securing better vessel support, through increased funding to allow commercial charter or via formal institutional collaborative arrangements, is desirable to maintain and improve access to the MPAs and should be part of the overall management strategy at Departmental level. Another challenge is that Australian Diving standards greatly reduce the amount of diving time available when greater than six hours from a recompression chamber. Consequently it is very difficult to design a sampling program which adequately covers the range of habitats in each reserve area. However, recent methodological advances in sampling equipment (e.g. towed video sleds) now mean it is possible to sample underwater communities, relatively inexpensively, without using SCUBA. Where possible, sampling should utilise these new technologies.

Sampling Framework

Recent surveys of Lihou and Coringa-Herald reserves by AIMS have used sampling designs that have spread the sampling effort widely in the shallow waters (6-9m) of each reserve (Oxley *et al.* 2003, Oxley *et al.* 2004b). These surveys provide a solid framework from which to develop a continued monitoring program for each of these reserves and should be used as a model for all of the other coral reef reserves. Efforts should be also made to extend sites to include a comprehensive sample of the habitats present, including deeper water areas, and in ongoing monitoring studies.

However, it is recognised that time constraints, due to poor weather, vessel operational constraints, and diving restrictions, make consistent sampling difficult in these isolated environments and consequently is it recommended that fewer sites be sampled more regularly. The value of long term monitoring is likely to come more quickly from consistent repeated sampling of fewer areas.

Who will undertake the monitoring?

After the costs of shiptime, labour costs are generally the most expensive part of a monitoring program. Consequently there will always be pressure to utilise volunteers, students, and DEH staff to assist in the work. This has proved successful in the sea turtle program conducted on the cays within the DEH reserves. Consideration has been given to the use of volunteers and students as possible assistants in a monitoring program for the Commonwealth MPAs and it is quite possible that given adequate competencies, personnel who are not engaged in a fee for service research arrangement with DEH can play an important role in Reserve monitoring. Such a role would be at a level different from the comprehensive surveys. However, there is some quality assurance and duty of care considerations for underwater monitoring that will require careful consideration for the following reasons.

While Customs has provided written advice to DEH that the qualification level of divers deploying from their vessels on DEH related work has nothing to do with them (DEH comm. to AIMS) , DEH will need to ensure that volunteers/contractors/ staff possess the required accreditation/competencies whether this be for SCUBA or any other activity. An internal DEH protocol is likely to be required to meet this need.

For comprehensive biodiversity surveys, highly experienced personnel who are able to consistently identify numerous species are required. Less stringent knowledge requirements may apply where just a few key indicators are monitored annually and which can be done effectively with snorkel. However the reliability of this data will need to be formally assessed by undertaking an analysis of inter-observer variability for the chosen indicators. Some indicators will be much more robust than others in this regard. Examples of taxa where limited skills are required for reliable identification could include COTS, clam, beche-de-mer and bleached coral.

Imaging devices such as video and still cameras are also used to collect data and this can relieve the in situ identification skill requirements. However coral data collected using video equipment also requires experienced divers, especially in areas where there is significant wave action. The Australian Institute of Marine Science has analysed large numbers of coral videos from volunteer groups and frequently the video quality has been too poor to return useful information. It has been shown repeatedly that quality video images are only obtained after training followed up by regular use of the technique. The use of a digital still camera equipped with a simple quadrat framing device is likely to be much less prone to operator error in capturing useful survey data and would be more amenable to use when snorkelling in very shallow waters. Such an approach does require development of a simple standard protocol that can be readily understood by non-specialist field personnel.

One objective of a monitoring program is to detect temporal changes in the abundance of key indicators through time and establish some criteria for what normal rates of change are. Large changes to the system as a whole need to be documented, but simple measures of abundance may not be informative from a management perspective without an understanding of process. It may be normal to observe extreme fluctuations in the abundance of key taxa, for example live coral or selected fish species, which limits their utility as indicators of ecosystem health unless long term data series are accumulated that capture natural cycles and additional indicators, such as demographic data on the same species, are also measured.

DIVING RESTRICTIONS FOR PROFESSIONAL SCIENTIFIC SURVEYS

Each agency in Australia involved in diving operations has its own set of diving procedures that they require their staff to follow. These procedures all have slight differences but in the vast majority of cases the DCIEM tables are used for dive planning and all scientific diving operations are conducted according to AS/NZS 2299. These dive standards impose significant restrictions on dive times when diving operations are performed greater than 6 hours from a chamber. These restrictions include reduced bottom time limits and restrictions on repetitive dives. The majority of the DEH Reserves are very isolated and therefore diving operations are significantly restricted. These restrictions have been taken into account when recommending scientific methods and suggesting levels of replication.

Recent research and monitoring, involving diving in the isolated Reserves, suggests the maximum amount of diving that can be routinely completed within a day, for multi day diving, is 4 dives of 45 min duration to a maximum depth of 9m (Oxley *et al.* 2003; Oxley *et al.* 2004a), reducing to 2 dives per day when deeper surveys to 18-20m have been required e.g. at Ashmore Reef (Rees *et al.* 2003). Consequently, , while a significant amount of data can be collected in very shallow water by snorkel, SCUBA diving effort is severely constrained by depth. It should be noted that significant areas of some Commonwealth Reserves lie in waters below 30m, which is the normal maximum depth for non-decompression scientific diving in Australia.

The use of non-diver based methods, such as deployed video and still cameras, removes the depth and operational safety constraints associated with diving, but demands specialised equipment and in some cases is not workable from Bay Class Customs vessels, e.g. ROV and towed video, without significant logistic complexity. While these tools do exist, surveys of the deeper waters are best supported with alternative vessels, such as research ships and chartered work vessels.

A COST-EFFECTIVE SAMPLING STRATEGY (HOW OFTEN?)

Background

There are three main time scales for reporting on the performance of the Commonwealth MPAS. The state of the marine parks, under the jurisdiction of DEH, is reported on annually in the DEH Annual Report, whilst legislation requires State of the Environment (SOE) reporting every five years (EPBC Act 1999). Management plans are in place for each reserve for seven years. These reporting time frames (1, 5 and 7 years) should be informed by real data, whenever possible. In addition, rapid response surveys outside the regular survey schedule, need to be accommodated when broad indicators suggest something irregular may be occurring.

Significant recruitment is known to occur on an annual basis for many biota in coral reef communities and consequently many larger scale studies have been conducted on an annual basis. An understanding of a reef community is only built up by repeated sampling over a number of years. However, the large costs of surveying isolated areas means that less frequent sampling is desirable.

A decision support framework is a useful means for structuring a flexible monitoring programme however, the basis of such a framework is knowledge and this is generally extremely sparse with many of the Reserves only ever surveyed once, or possibly twice. Therefore the first priority must be to build this information base to increase the understanding of the 'natural state' of the Reserves. As this knowledge develops the capacity to refine the monitoring will increase. The decision framework to prioritise research for Shark Bay (Simpson *et al.* 2002), attributes priorities based on rankings to major biodiversity indicators, the threats they face and the state of knowledge. A similar approach could be adopted for each of the Commonwealth MPAs

SUGGESTED SAMPLING REGIME

Experience on the Great Barrier Reef has shown that sampling at intervals of greater than one year apart can result a monitoring program missing large scale changes to reefs and the longer the time before detection the more difficult it is to discover what caused the change. Without this knowledge it is hard to decide on any management actions that may be required as a result of that change. The need to contain the costs of monitoring is recognised and so a two level monitoring program has been devised.

It is recommended that the Reserves be visited and monitored at least annually.

These annual visits could be conducted in three days and would only require a two person dive team. Every 3-5 years a full monitoring survey should be conducted within the Reserves timed to fit with SOE reporting requirements and management plan revisions where possible. If the short annual visits reveal unusual or inexplicable change, then consideration should be given to conducting a full survey as soon as possible to allow for a more thorough investigation of the Reserve. This strategy is outlined in a flowchart (Figure 2).

During the annual surveys the two divers would assess a few key indicators (see below) at each, complete survey transects at several sites, take representative photos of the Reserve communities, and change over any deployed data logging devices. If the key indicators showed no unusual change from the previous visit (e.g. no "large number" of crown-of thorns starfish, no "dramatic" coral loss, no bleaching, no loss of large predators) then a SHORT report would be provided to DEH. General panoramic video footage should also be taken and archived.

These data should be analysed and for each Reserve a short update report submitted to DEH comparing the data to previous visits. These reports should also contain graphs of the SST data. Following review by DEH these reports should be placed on a public access website with accompanying photographs and the data archived. However, if the key indicators revealed significant deleterious change within the Reserve then recommendations would be provided to DEH on what action to take. If any key indicators reveal significant changes then this could trigger an earlier full sampling visit. If the short annual surveys showed no significant impacts then a full survey would be scheduled every 3-5 years, timed to provide information for the Reserve management plan review. These full surveys should collect detailed information on the 'health' of the fish and coral communities and other key benthos including beche-de-mer, and giant clams (see below). If technically feasible, future surveys would expand to include observation the deeper areas of the Reserves.

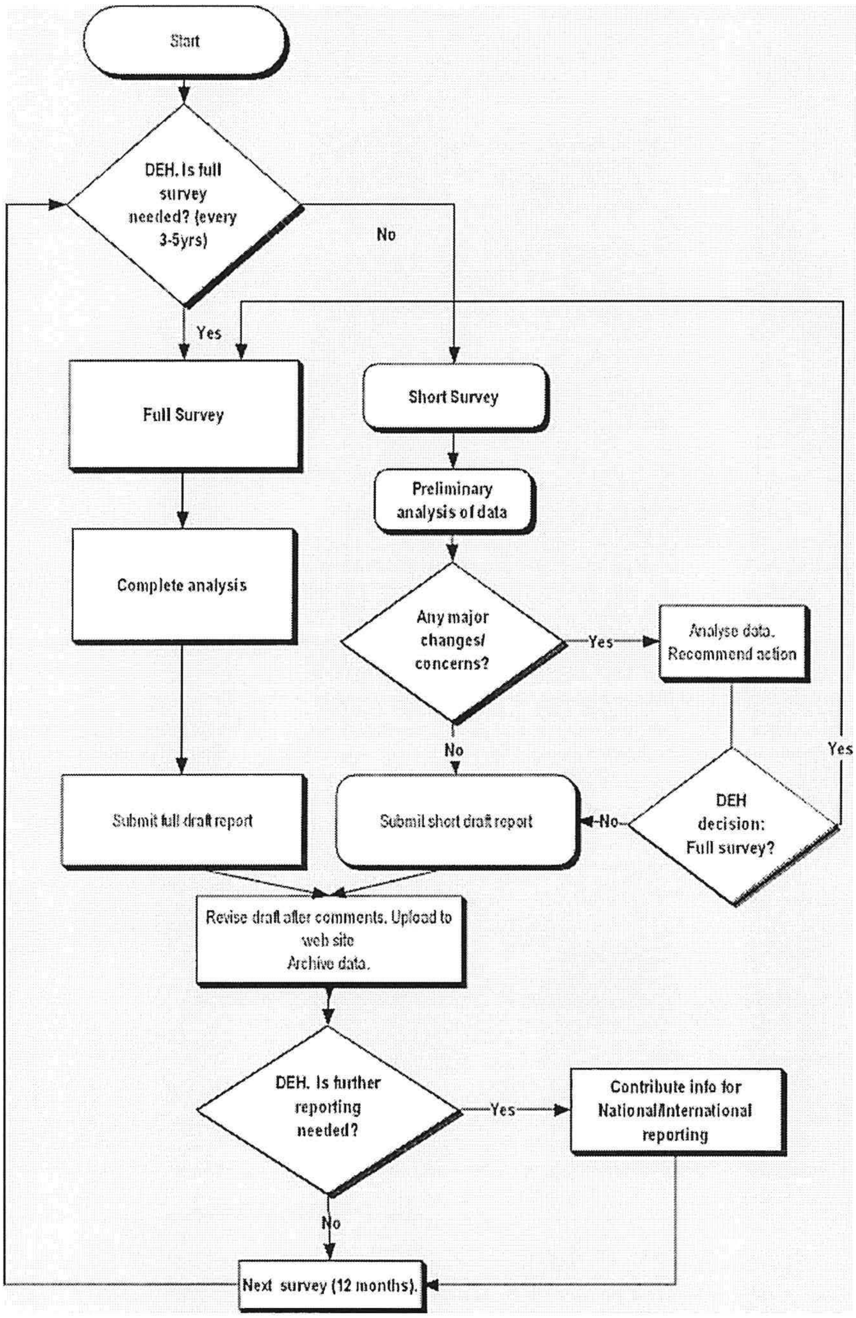

FIGURE 2. Flowchart for decisions regarding timing and type of monitoring survey required in each Reserve.

Standard Methods and Performance Indicators

PERFORMANCE INDICATORS

The concept of indicators for assessing coral reef health has received widespread attention (Jameson *et al.*1998, Ward *et al.* 1998, Pomeroy *et al.* 2004). There is plenty of debate about the 'best' indicators of reef health and the decision is generally a trade off between finances and the usefulness of the data collected. Percentage of live hard coral cover and some measure of benthic diversity are two environmental indicators for ecosystem status which have received widespread acceptance and many coral reef monitoring programs focus on these parameters (See Sweatman *et al.* 2003, Wilkinson *et al.* 2003, Wilkinson 2004). These indicators are of most use for management decision support once they have captured variability over the long term, typically a decade or more. Short term indicators include estimates of recruitment and post-recruitment mortality and the abundance of species under pressure, e.g. targeted fisheries stocks.

Estimates of coral bleaching, crown-of-thorns starfish densities, *Drupella* densities, SST measurements, and wind speed all provide information which increases the understanding of the causes of past change. Collection of demographic (recruitment, growth, mortality) data improves the understanding of the population dynamics of the community and this knowledge helps in the predicting the potential for recovery after disturbance. For example a reef with very low coral cover but evidence of a large pulse of tabulate *Acropora* coral recruits would be expected to show a significant increase in coral cover within five years in the absence of another significant disturbance.

Similarities between demographic data from populations on geographically isolated reefs can also suggest reproductive links, even though they may be separated by 10s or even 100's of km. Reef fish demography requires that the animals generally be killed to extract the otoliths (ear bones) and for obvious reasons this is not desirable in marine protected areas, except for very small numbers of fish relative to the population size of that species on that reef. Genetic tools have also been developed to provide DNA-based analysis of connectivity between coral populations. At present the methods work with a limited number of species, but enough to provide broad indications of levels of connectivity and reliance on self-seeding for these reef systems.

The indicators suggested for the coral reef reserves are shown in Table 1.

Table 1. List of indicators and the method used to obtain these indicators. At least one reference which describes the method is provided. The last column indicates a recommendation for when the data should be collected. S=short survey (not included in the table), St= truncated sampling during short survey, F=full survey, C=continuous.

Indicator	Method	Reference	Survey
% Live Hard Coral Cover	Video transects	Page *et al.* (2001) Hill & Wilkinson (2004)	St,F
Benthic cover and diversity	RAP (Rapid assessment protocol)	Devantier *et al.* (1998) Oxley *et al.* (2004a)	F
Colony size	RAP	Devantier *et al.* (1998) Oxley *et al.* (2004a)	St,F
Coral bleaching	Belt transect	Miller (2003)	St,F
Coral diseases	Belt transect	Miller (2003)	St,F
Physical damage	General notes and video panoramas	Page *et al.* (2001)	St,F
Beche de mer, giant clam, densities	Manta tow, Belt transect, Snorkel swim	Oxley *et al.* (2004a)	St,F
Crown-of-thorns densities.	Manta tow, belt transect snorkel swim,	Miller (2003) English *et al.* (1997)	F St,F F
Densities of key large fish and shark species	Timed swim Fish RAP	Choat & Pears in Wilkinson *et al.* (2003)	St, F
Fish abundances	Fish RAP	Williams (1982)	F
Sea Surface temperature (additional oceanographic instrumentation as required)	Temperature loggers	Reef Futures (2004)	C
Deep Benthic Cover	Towed video Drop camera	Speare *et al.* (2004)	F
Fish/Shark numbers	Baited Remote Underwater Video System (BRUVS)	Cappo *et al.* (2003, 2004)	F

Standard Methods

In a monitoring program, especially one that seeks to make regional comparisons between reserves, the critical issue is for the methods used to be consistent, both between regions and over time and to simultaneously monitor indicators of pressure on these systems.

If the methods used are not consistent then establishing real change from differences introduced by alternate methods becomes very difficult or even impossible. This is well understood by the scientific community and, for shallow water coral communities, there are a number of well established scientific methods in widespread use across Australia and the world e.g. English *et al.* (1997), Brown *et al.* (2004). Most of the Commonwealth MPAs have now been surveyed at least once using well established standard methods. These methods are also used in the Australian Institute of Marine Science Long Term Monitoring Program which has been conducting large scale surveys of the fish and benthic communities of the Great Barrier Reef since 1992. This program is the largest of its type anywhere in the world and the use of these methods in the Commonwealth MPAs allows direct comparisons to be made with Australia's largest reef system. It is therefore highly recommended that all future surveys of the Reserves use these methods as described and referenced below. This will allow unbiased biogeographic comparisons of biological assemblage diversity between all the DEH Reserves with coral reefs habitats and with other reefs systems in the Indo-Pacific region, in particular the GBR.

The coral reef reserves also contain deeper water habitats that are not accessible using diver based survey methods. For this reason, to date, these areas of the reserves have received little or no attention and it is not yet clearly established what communities exist at these depths. A range of traditional destructive sampling techniques, such as trawls and grabs remains the most useful approach o establishing species inventories in deeper water. More recent non-destructive approaches involve the use of deployed imaging equipment or reliance on proxies, such as acoustic returns, for mapping of high-level values such as habitat extent. Many of these techniques have been developed with larger research or industry ships as support platforms, making costs high, but refinements and innovations are creating smaller gear, able to be deployed from smaller vessels or ships of opportunity and are likely to be more useful, under tight fiscal constraints requiring flexibility in vessel use, for survey of deeper areas in the coral reef reserves. A combination of high-resolution acoustic methods to map depth, seabed texture and hardness, backed up with the limited video validation, would deliver a cost effective and comprehensive habitat map of the greatest use in identifying the most likely biodiversity hotspots.

A brief outline of the methods and links to standard operating procedures, reports or papers detailing their use is provided.

Benthic Rapid Assessment Protocol (RAP) using scuba and snorkel

This is a rapid visual assessment method for reef benthic abundance and diversity developed by DeVantier (see DeVantier *et al.* 1998) which has been used extensively throughout the Indo Pacific. The method has already been adopted in surveys of Elizabeth Middleton, Coringa Herald and Lihou Reef Reserves (Oxley *et al.* 2003, 2004a,b).

Using this method the abundance of categories such as hard corals, all soft corals, all sponges and all thallous algae is able to be estimated using a five point scale. Benthic data are collected to species level where possible and this provides a measure of the biodiversity of the benthos.

In addition estimates are made of the proportion of colonies in three size classes: 1. <10 cm across; 2. 10-50 cm across; and 3. >50 cm across. This provides some measure of the age of the community and the presence of recruits.

The major benefit of this type of data is that species level and size class information is gained from a site in a short space of time and these data provide a broad indication of the benthic biodiversity through time. It is stressed that the method requires highly experienced observers and is open to major issues of observer bias between surveys. This can be minimised by the use of close up digital photography and voucher specimens as discussed in Oxley *et al.* (2004a). The collection of size class data can give an indication of the sustainability of communities and the potential for recovery after disturbance.

Video transect surveys

Video surveys are used to obtain "rigorous abundance" estimates of biota at a coarser taxonomic resolution. They should be carried out following a standard operational procedure currently used in long term monitoring surveys of the GBR. The method has received wide acceptance, both nationally and internationally, and is described fully in Page *et al.* (2001) and Osborne and Oxley (1997). Use of this method will allow direct comparisons to be made with existing data from the GBR and provide a solid baseline against which future change can be measured.

Corals should be identified to the greatest taxonomic detail achievable, though it is likely that they will be aggregated for analysis. Generally analysis of the video data should focus on four major components of the benthic community: hard corals, soft corals, algae and sponges. Species level information on coral communities can be obtained using the RAP described above.

At each site 360° panoramic shots should also be filmed over a 30-60 second time period before each transects is sampled. These panoramas provide a contextual view of the topography and habitat in which transects are laid.

Fish rapid quantitative survey method

The rapid quantitative survey method is a timed swim fish count for large vulnerable reef fishes. A suitable method is described by Choat and Pears (in Wilkinson *et al.* 2003). The species list for this method should include at least sharks, napoleon wrasse (*Cheilinus undulatus*), humphead parrot fish (*Bolbometopon muricatum*), large cod, and coral trout. These species are representative of key trophic groups. The large predators such as sharks and coral trout may also be susceptible to fishing and their abundance and size can provide an indicator for fishing pressure. With experienced observers this method can provide useful density estimates for these larger fish species in the Reserves.

A more detailed rapid visual census (modified from Williams 1982) has been used to describe the fish fauna at several of the coral reef Reserves (Oxley *et al.* 2003, 2004a,b) but this method is not considered suitable for routine monitoring especially given long time period between surveys.

Two methods are suggested for measuring the abundance and distribution of beche-de-mer, crown-of-thorns starfish, giant clams and coral bleaching: snorkel swims and SCUBA searches. The SCUBA search method also provides information on *Drupella*, coral bleaching and coral disease. In areas where Trochus are present, they should also be included in the surveys. The suggested species list for beche-de-mer is shown in Table 2. These trochus, beche-de-mer and clams are potential targets for fishing activities, for example at Ashmore Reef, Cartier Island and Mermaid Reef. Crown-of-thorns and *Drupella* are corallivorous predators that are known to occasionally reach plague proportions and cause massive coral mortality.

These methods have been used successfully to survey all of the Coral Reef Reserves and the methods are described in detail in the reports (Smith *et al.* 2001,2002, Rees *et al.* 2003, Oxley *et al.* 2003, 2004a,b).

Snorkel swims

Snorkel swims can be used to survey the shallow waters of the Reserves in the lagoons, back reef and reef flat habitats. Observers record numbers of bêche-de-mer, crown-of-thorns starfish and giant clams. Details of the method can be found in Oxley *et al.* (2003).

Table 2. Suggested list of bêche-de-mer species for sampling and rationale for their selection.

Species	Common name	Rationale for inclusion
Holothuria whitmai (nobilis)	Black Teatfish	Key commercial species. Widespread Indo-west Pacific, Lord Howe, northern Australia.
Actinopyga mauritania	Surf Redfish	Recorded in MPAS, GBR. Commercial species
Actinopyga other	Blackfish	Observed in MPAS, GBR. Commercial species
Holothuria atra	Lollyfish	Widespread Indo-west Pacific, Lord Howe, northern Australia.
Stichopus chloronotus	Greenfish	Observed in MPAS, GBR.
Thelenota ananas	Prickly Redfish	Widespread Indo-west Pacific, Lord Howe, northern Australia. Commercial species
Holothuria fuscogilva	White Teatfish	Observed in other MPAS, GBR. Commercial species
Holothuria scabra	Sandfish	Key Commercial species. Observed in other MPAS, GBR.
Stichopus hermani (variegates)	Curryfish	Observed in other MPAS, GBR.
Bohadschia argus	Leopardfish	Observed in MPAS, GBR.
Holothuria edulis	Pinkfish	Widespread Indo-west Pacific, northern Australia. Observed in MPAS
Thelenota anax	Amberfish	Observed in other MPAS, GBR.
Holothuria leucospilota/ coluber	None /Snakefish	Observed in other MPAS, GBR.
Holothuria impatiens	Tiger Tail	Widespread Indo- Pacific, northern Australia. Observed Elizabeth Middleton Reserve.

SCUBA SEARCHES

SCUBA searches provide information on numbers of beche-de-mer, crown-of-thorns starfish (COTS), *Drupella* (a coral eating snail) and other sources of coral mortality (especially coral bleaching) to assist in interpreting benthic cover estimates. SCUBA searches provide a more detailed picture of the causes and relative scale of coral mortality than is possible with video techniques. The technique is described in Oxley *et al.* (2004a).

Table 3. Data collected using SCUBA search method.

Holothurians	Total count by species
Crown of thorns starfish	Total count in 3 size classes
Crown of thorns starfish scars	Total count
Drupella spp	Total count
Drupella scars	Total count
White syndrome disease scars define	Total count
Blackband disease scars define	Total count
Unknown scars	Total count
Coral bleaching	Estimate of bleaching as a percentage of live coral cover

TOWED VIDEO AND STILL CAMERA

Towed video techniques are used to access deeper water benthic habitats, typically at below diveable depths. A colour video camera is mounted on a vane and connected via a live cable to the ship. Underwater lights are typically used to illuminate the field of view and improve the images. The camera is controlled by operating the winch which deploys and recovers the cable. Visual imagery of the benthos is recorded on a video machine on board for post processing. The video should be interfaced with a GPS to facilitate real-time geo-referencing of all data points Computer-based application allow keyboard classification of substrata, benthos and individual organisms in real time.

Higher resolution imagery from the bottom can be obtained by the use of a hi-resolution digital still camera and strobe. The still camera should be mounted to the towed body and set to record a still image at set intervals. A drop camera or ROV can be used to target specific areas identified by towed video that warrant further investigation. If high quality, controlled video transects can be achieved, the images can be analysed using the methods described in English *et al.*(1997) and Page *et al.* (2001). These are the methods used to analyse the diver collected videos.

BAITED REMOTE UNDERWATER VIDEO SYSTEM (BRUVS)

BRUVS allow examination of deeper water fish stocks beyond the time limits of scientific diving practice. In offshore environments using natural light, useful data can be obtained with standard video cameras to depths of approximately 100m. Deeper water surveys and surveys in low light or at night require illumination sources, but the presence of lights may introduce additional sampling artefacts. One of the great advantages of the BRUVS method is that the sampling is non-extractive and does not cause damage to the seabed (Cappo *et al.* 2003). Another advantage is that using the video allows the habitat of the sampling area to be determined. The videos are baited and record species that are attracted either by the bait or by the commotion caused by other fish feeding and aggregating at the station. The method is described in detail in Cappo *et al.* (2003).

UTILITY OF REMOTE SENSING FOR MONITORING

All of the current Commonwealth coral reef reserves exist in clear waters and consequently remote sensing is often promoted as a tool for assessing the extent and status of coral reefs. Remote sensing has been used successfully internationally to map coral reef boundaries, investigate geomorphologic zonation and determine depth (Mumby *et al.* 2004, Stumpf *et al.* 2003, Spalding *et al.* 2001). However optical remote sensing has proven to be severely limited in measuring changes in coral communities and has only been successful at this in shallow reef flat environments (Green *et al.* 2000). Green *et al.* (2000) report that low altitude aerial photography has been the only successful remote sensing method for providing synoptic data on coral colonies and live coral cover (see Catt and Hopley 1988, Thamrongnawasawat and Catt 1994). They indicate that its use is largely confined to assessing the coral cover of emergent and extremely shallow reef flats at low tide due to the poor depth of penetration (< 1 m) (Hopley and Catt 1989). Relatively new satellites with very high resolution (Ikonos, Quickbird) have been used successfully to map reefs but the accuracy was not high when specific habitats were targeted (Mumby and Edwards 2002, Andrefouet *et al.* 2003). Recently, hyperspectral imagery, collected from aircraft, has been used in Hawai'i to map coral reefs and potentially identify areas of dead coral (Field *et al.* 2001). However as with all successful remote sensing, divers are required to calibrate and help interpret the remotely collected imagery and this is very time consuming (Bainbridge and Reichelt 1989). In summary, while remote sensing has proven itself as a reliable tool for relatively coarse mapping of reef communities it is not yet considered feasible for collecting routine biological monitoring data from the coral reef reserves, but is an actively developing field and should be re-evaluated periodically. Access to the Commonwealth MPAs does provide an excellent opportunity for ground truthing satellite imagery and development of a collaboration with remote sensing scientists could form the basis of a useful research exercise of potential benefit to management.

Remote sensing can provide physical data at scales that are appropriate for assessing effects on the coral reef reserves. Satellites currently provide data on a variety of physical parameters (Mumby *et al.* 2004). Three of these parameters are considered very useful for assessing their role in observed changes in the isolated coral reef reserve ecosystems: sea surface temperature, wind speed, and wave height. These data are collected daily by organizations such as NOAA and AIMS and in some cases the data are available at no cost (http://manati.orbit.nesdis.noaa.gov/quikscat/) for twice daily global ocean wind speed data). Consideration should be given to archiving these data to greatly improve interpretation of the biological data collected annually. These physical data may provide strong evidence for the cause of observed changes.

The Potential for Community Involvement

While regular community participation in environmental monitoring is not considered appropriate for quantitative monitoring of the coral reef reserves, general observations may be of use in providing early warning of significant change in status of dominant biota. In addition, community monitoring is recognised as a valuable tool to encourage increased stewardship for, and understanding of, local environments and of change in those environments (e.g. ReefCheck www.reefcheck.org). Community and volunteer involvement works best where there is easy access to the areas of interest. The methods of data collection need to be relatively inexpensive and the methods have to be easily taught and robust enough to ensure consistency and quality in the data collected.
There are a number of examples of successful community involvement in coral reef monitoring and several of these could be applied in the coral reef reserves when they are visited by commercial operators such as dive charter companies. An example of successful community involvement is the COTSWATCH program within the GBR Marine Park (http://www.gbrmpa.gov.au/corp_site/info_services/science/cots/). This program encourages reporting of observations of crown-of-thorns starfish through an easy online reporting system. The information obtained through this program has greatly assisted the efforts of researchers and managers by indicating the occurrence of COTS in areas not frequented by researchers. This early warning system has allowed more detailed scientific follow up as required. With the increase in coral bleaching on coral reefs a new program, BLEACHWATCH has been established (http://www.gbrmpa.gov.au/corp_site/info_services/science/bleaching/bleach_watch.html) along similar lines to COTSWATCH. These types of programs should be considered for Commonwealth MPAS where there is periodic visitation by tourists, and other visitors such as commercial fishers. It should be noted that successful volunteer programs require good coordination and this is generally a paid position (e.g. Reef Check in Australia) or coordinated by an individual in a government position associated with the MPA (e.g. COTSWATCH at GBRMPA). Therefore it is suggested that any programs such as these planned for the coral reef reserves, should be linked in with existing programs to ensure their sustainability.

Priority Areas for Research

GUIDING PRINCIPLES

All the Reserves considered by this tropical strategy have been assigned the IUCN protected area management category 1a- strict nature reserve. IUCN (1994) define a category 1a nature reserve as an "Area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring". The management plan for each of the Reserves goes further with a stated objective in each plan that they should be managed "as a reference site for scientific research and long-term monitoring". However, it is clear that any permitted research should not be in conflict with the overriding objective for each of these 1a strict nature reserves which is to "maintain ecological processes and systems and to protect the habitats and biodiversity of the Reserves from the pressures associated with human use" (Commonwealth of Australia 2002b).

One of the management strategies outlined in each of the management plans is to 'develop cooperative arrangements with research organisations to conduct research and monitoring activities that will increase knowledge, enhance management, and which are consistent with the management objectives for the reserves'. A useful prioritisation matrix should be developed for each MPA and may be evolved along the lines of that used for the Shark Bay world heritage area by Simpson *et al.* (2002). Firstly all relevant data related to the MPA are assembled and reviewed. The key ecological, social or economic values, including any specific declare values for the MPA, are then assigned a value on a nominal five point scale for state of knowledge, level of threats and pressure. The resulting numerical ranking for each value, while notional, does provide a very useful first level prioritisation into high, medium and low for the MPA values and associated research and monitoring issues.

These commonwealth reserves also fall under the Environment Protection and Biodiversity Conservation Act 1999 (hereafter EPBC Act) and this Act imposes a range of controls and restrictions on activities in the Reserves (Commonwealth of Australia 2002b).

CONNECTIVITY

One of the largest gaps in our understanding of the ecology of coral reef fish and coral populations is a thorough knowledge of the spatial scales on which populations operate (Sale 2002, Buddemeier and Fautin 2002). The extent of dispersal of larval fishes and corals and the pattern of interconnection of local populations is vitally important for the "effective implementation of spatially explicit management Scientists are using a variety of means to tackle these questions including the use of genetic techniques to examine gene flow and infer interconnectivity and multidisciplinary work between oceanographers and ecologists and these studies should be encouraged. The isolation of the tropical marine reserves makes them ideal candidates to support this type of research and this research should be regarded as high priority.

CORAL BLEACHING

Coral bleaching looms as one of the major threats to the worlds' coral reefs (Hoegh-Guldberg 1999, Hughes *et al.* 2003). It is clearly of major concern in the coral reef reserves with five of the six reserves experiencing coral bleaching in the last 6 years, with severe beaching observed in three of the reserves. Recent marine research on coral bleaching has focused on the ability of corals to adapt or acclimate in response to increased sea surface temperature (SST). There are strong suggestions that some zooxanthellae (the symbiotic algae living in coral tissue) are more resistant to increases in SST than others, and this line of research may provide insights into why some corals do better in bleaching events (Fabricius *et al.* 2004). Research in this area should be regarded as high priority.

Coral reef resilience

Coral reefs are declining worldwide and this has led to increased research interest in the concept of coral reef resilience (the ability of a reef to recover after disturbance). An improved understanding of the dynamics of a coral reef ecosystem and the processes that promote or retard resilience will greatly improve the ability of DEH to actively manage their marine protected areas. Examples of work in this area include research by Bellwood *et al.* (2004), Halford *et al.* (2004), Heyward *et al.* (2002). This should be regarded as high priority research.

Effectiveness of MPAs

As discussed above, the effects of management protection of a MPA can only really be assessed by concurrent monitoring of similar areas outside of the MPA.

Research work that seeks to compare the coral reef reserves with other areas outside the reserves over time, as a direct test of their effectiveness, should be strongly encouraged and supported as a high priority. Examples of work in this area include Edgar *et al.* (2004), Mapstone *et al.* (2004), Russ *et al.* (1995) and Russ *et al.* (2004).

Other important avenues of research

The following areas of research are also considered important and suitable for support in the Commonwealth coral reef reserves:

- **Taxonomic research.** This is the foundation of all other aspects of biological research and provides important information on biodiversity.
- **Deeper water habitat mapping**. Little is known about the deeper water reef and inter-reef areas of the reserves. Habitat mapping would provide important information on these areas and provide a solid foundation for future monitoring.
- **Acoustics**. This is an area receiving increase attention. Targeted acoustic work could provide a useful tool for monitoring of marine mammal populations. Acoustics have also been used in other marine reserves as a surveillance tool to assess illegal visits and this may have applicability for the Commonwealth reserves.

This list should not be considered exhaustive and merely provides examples of areas of research that are regarded as important and useful in support of effective management of the Commonwealth marine protected areas.

Data Handling Procedures (including data access)

DATA STORAGE

All data resulting from these surveys should reside in a central database and the public should be provided with interactive access to parts of these data. An example of environmental coral reef data where this presently occurs is the Reef Monitoring Database maintained at the Australian Institute of Marine Science (AIMS) (Baker and Coleman 2000). Access to this extensive database is available via the AIMS web site (www.aims.gov.au).

ELECTRONIC MEDIA

Video has been used in previous surveys of Commonwealth MPAs, its used is increasing and it is anticipated that video images will form a significant part of the future sampling. The resulting videotapes should also be stored at key locations within each region according to established procedures for storing electronic media. (National Archives of Australia 2004). Backup copies should be archived with the National Archives office in Canberra.

It is anticipated that the growth in broadband nationally and internationally will mean that the growth in this area will be substantial over the next decade and so development in web access systems should anticipate this. A subset of the video images should be made available via the web.

Photographs represent an extremely valuable record of surveys but are often difficult to locate or retrieve after time. Consequently a representative selection of photographs from each survey should be data based and stored electronically for future reference. A selection of images should be made available via the web.

DATA ACCESS AND PRESENTATION

The reports and information resulting from surveys should be accessible from a central web site. Where possible and appropriate, the public should be provided with interactive access to parts of these data. An example of environmental data where this presently occurs is the Reef Monitoring Database maintained at the Australian Institute of Marine Science (AIMS) (Baker and Coleman 2000). Access to this extensive database is available via the AIMS web site (www.aims.gov.au/reef-monitoring).

LINKING WITH OTHER DATABASES

There is a variety of information in databases nationally and internationally which is relevant to research and monitoring of the coral reef component of tropical Commonwealth MPAs. The use of data standard would allow data collected to be linked with these databases. For example the datasets could link in with the "Oceans Portal" that is being developed by the National Oceans Office (National Oceans Office 2004). The intention is that this "Oceans Portal" and its associated infrastructure will connect marine datasets from a number of Australian Government organisations through a distributed system, using the Internet.

Reporting Framework

Access to the information arising from monitoring is important and so reports should be accessible via a central web site. Extensive use should be made of photographs, graphs and other visual methods to highlight trends and key findings from the work. Direct links should be made between results from the surveys and DEH performance assessment indicators. This has been successful in performance assessment on the Great Barrier Reef where one of the Key Performance Indicators for the GBR Marine Park is directly linked to information derived from annual survey reports provided by the Australian Institute of Marine Science (See Day *et al.* 2002, and Sweatman *et al.* 2003).

The Environment Protection and Biodiversity Conservation Act 1999 requires a report on the environment in the Australian jurisdiction to be prepared every five years. This requirement is fulfilled by the State of the Environment Report. The next report is planned for the 2nd half of 2006. A process to ensure information arising from monitoring of the MPAs feeds directly into the SOE process should be identified (Figure 2).

There are also standard international reporting systems which the Coral Reef Reserve information can feed into and this should be a contractual requirement. The Global Coral Reef Monitoring Network produces biannual reports on the Status of Coral Reefs of the World and data collected from the Commonwealth coral reef reserves already feeds directly into this reporting system. (Wilkinson 2002, 2004). Reefbase is a global information system on coral reefs and this also is a natural home for data arising from monitoring of the Reserves (http://www.reefbase.org/)

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Appendix 1. Coral Sea National Nature Reserves

The primary objective of the Coral Sea National Nature Reserves (Coringa-Herald and Lihou), as stated in the management plan is "to maintain ecological processes and systems and to protect the habitats and biodiversity of the Reserves from the pressures associated with human use" (Commonwealth of Australia 2001).

The strategic objectives for the Coral Sea National Nature Reserves are listed as follows: "to:

- Protect, preserve, and manage the natural and cultural values of the Reserves, including the marine and terrestrial wildlife, and objects and sites of biological, historical, palaeontological, archaeological, geological and geographical interest from human induced damages.
- Protect key breeding and nesting habitat for listed species such as green turtle and seabirds.
- Manage the Reserves as a reference site for scientific research and long-term monitoring.
- Allow for limited public access to the Reserves for education and enjoyment, in a way that does not interfere with the natural and cultural values, or key breeding sites for nesting species within the Reserves.
- Manage the Reserves as part of a comprehensive, adequate, and representative system of marine protected areas to contribute to the long-term ecological viability of marine and terrestrial systems."

This strategy is concerned with achieving objectives 1, 3 and 5.

Ashmore Reef and Cartier Island Reserves
According to the management plan, the Ashmore Reef and Cartier Island Reserves were established by the Commonwealth for the purposes of protecting their outstanding and representative marine ecosystems and to facilitate scientific research (Commonwealth of Australia 2002a).

The strategic objectives for Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve are to:

- protect the high conservation values in the marine and terrestrial environments of Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve;
- manage the Reserves as part of the National Representative System of Marine Protected Areas;
- contribute to the protection of the overall conservation values in the Oceanic Shoals Bioregion;
- facilitate research on the ecology of the Reserves and the Oceanic Shoals Bioregion;

- provide biological refuges that will contribute to an integrated management framework for the sustainable use and long term protection of marine resources in the MOU Box.

Mermaid Reef Marine National Nature Reserve

The strategic objectives for Mermaid Reef Marine National Nature Reserve (Commonwealth of Australia 2000) are to:

- manage the area as part of a comprehensive, adequate and representative system of marine protected areas to contribute to the long-term ecological viability of marine and estuarine systems;
- ensure the preservation of Mermaid Reef in its natural condition and the protection of its special features, including objects and sites of biological, historical, paleontological, archaeological, geological and geographical interest;
- protect, conserve and manage the wildlife in the Marine National Nature Reserve;
- protect the Marine National Nature Reserve against damage; and
- encourage and regulate the appropriate use, appreciation and enjoyment of the Marine National Nature Reserve.

Elizabeth and Middleton Marine National Nature Reserve

The prime objective of the Elizabeth and Middleton Reefs Marine National Nature Reserve stated in the management plan "is the protection of the marine habitats and wildlife." (Commonwealth of Australia 1993).