JNCC Report

No. 455

A global review of long-term Marine Protected Area monitoring programmes: The application of a good framework to marine biological monitoring

Volume 1: Main Report

Volume 2: Appendix 1 – 4

A report prepared for JNCC by:
Prue Addison, School of Botany,
University of Melbourne, Australia

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Contents

List of Tables

List of Figures

Author’s Note

The following review has been produced for JNCC contract number T10-0208-0364 (TITLE: Contribution to research investigating the applicability of new statistical methods for the analysis of marine monitoring data). JNCC and I agreed on this contract on 30 November 2010, to support the first stage of my PhD research: A review of statistical techniques used within marine monitoring programmes. The following list outlines the aims and objectives of this review (as described in T1002080364 Annex A.doc):

1. Global scale investigation of monitoring programmes, with particular focus on Australia and the USA (JNCC’s primary interest), but European approaches will also be included (for Prue’s PhD).

2. The review will be limited to the most significant large-scale monitoring programmes, and will not focus on small scale monitoring unless considered necessary.

3. The emphasis of the review will be on the analysis of data, but background information such as the sampling design will also be included:

    a. What are the questions (if any) that the monitoring programme is designed to answer?
    b. How is monitoring programme designed: What data are collected; Spatial and temporal replication of collected data; who collects the data?
    c. How are results (following analysis) reported?

4. Additional information which JNCC would benefit from:

    a. A summary of the governance and management of each monitoring programme.
    b. Contact information for key individuals and organisations.

5. The report shall follow the JNCC report template, and be delivered in word and pdf format, with any accompanying files.

6. The support of JNCC will be acknowledged in any publications from this work.

7. The work is anticipated to take in the region of four months. A draft will be received by 1 March 2012 and the final report will be produced by 30 April 2012.

The final review delivered to JNCC is entitled “The application of a good monitoring framework to marine biological monitoring: A global review of long-term Marine Protected Area monitoring programmes”. The scope of my review is clearly more specific than the general aims and objectives described above.

The scope of my review has been narrowed to allow for meaningful and concise comparisons of global marine monitoring case studies. Some of the key aspects of my PhD research which were covered in this review included:

- Monitoring programmes that are **current** and involve the collection of **long-term** (greater than five years), **biological** datasets from the **marine** environment; and
- Monitoring programmes associated with a **government agency** (i.e. monitoring of an area or activity under government jurisdiction).

Based on the above requirements, two broad types of marine monitoring could have been reviewed: environmental impact assessment (EIA)/ threat assessment monitoring (e.g. for compliance), or conservation monitoring (e.g. associated with biodiversity protection). I decided to focus on just one of these types of monitoring: conservation monitoring associated with Marine Protected Areas (MPAs), for the following key reasons:

- There is a large pool of literature relating to MPA monitoring, which includes many famous examples of long-term MPA monitoring programmes, particularly from Australia and the USA (JNCC's primary interest).
- The primary aim of MPAs is the protection of marine biodiversity. I therefore considered that my review of approaches to monitoring marine biodiversity would be of direct relevance to JNCC's upcoming Marine Biodiversity and Surveillance Monitoring Programme.
- The conservation objectives and biological elements monitored within MPAs are comparable. These similarities mean that case studies in my review were well suited to global comparison.
- MPA monitoring results are predominantly presented in government reports and scientific papers. These resources are publicly available and more accessible than EIA related monitoring reports which can be more difficult to access.

Further details about the selection criteria for the MPA monitoring programmes that were included as case studies in my review can be found in section 3.1 and Table 1.

Although my review focuses on MPA monitoring case studies, I have made comparisons to marine EIA and experimental marine ecology literature throughout. I have also presented many EIA monitoring programme examples and highlighted the very traditional statistical techniques which are used by marine ecologists (section 5.3 of the Discussion; **Appendix 3** and 4). Essentially monitoring design, data collection methods and statistical techniques used in marine monitoring programmes are very similar, regardless of the type of monitoring (e.g. conservation vs impact assessment). However MPA monitoring literature makes very little use of the wealth of literature relating to issues with monitoring in the highly variable marine environment and problems with statistical inference (e.g. Type I and II errors) which can affect the interpretation of monitoring data.

My review is based on eleven case studies which are considered best-practice examples of long-term MPA monitoring programmes from around the world. These case studies are evaluated against the key components of a good monitoring framework. The current issues associated with these case studies and the lessons learned from other fields of marine and environmental research are discussed in detail. The issues with monitoring and lessons learned highlighted throughout this review are applicable to all types of environmental monitoring. The issues and lessons learned from this review should help improve the scientific credibility and success of current and upcoming marine monitoring programmes.

Acronyms

ANCOVA - Analysis of co-variance
ANOVA - Analysis of variance
ARR - Average response ratio (used in Case Study 8)
CAP - Canonical Analysis of Principal coordinates
CREMP - Coral reef evaluation and monitoring project (Case Study 9)
CROP - Cape Rodney to Okakari Point (Marine Reserve in New Zealand)
EIA - Environmental impact assessment
EM - Ecosystem monitoring (Case Studies 5 and 6)
GMMR - Generalized mixed model regression
HRHP - Healthy Reef Healthy People (associated with the Mesoamerica Reef, potential Case Study A2.12)
IRMP - Intertidal reef monitoring program (Case Study 4)
JNCC - Joint Nature Conservation Committee
KFM - Kelp forest monitoring (Case Study 8)
LMEM - Linear Mixed Effect Models
LTMP - Long term monitoring program (Case Study 1)
MDS - non-metric Multi Dimensional Scaling
MP - Marine Park
MPA - Marine Protected Area
NGO - Non-Government Organisation
NMP - National Marine Park
NMS - National Marine Sanctuary
NPS - National Park Service (in the USA)
NSW - New South Wales (in Australia)
PCA - Principal coordinate analysis
PERMANOVA - Permutation analysis of variance
PISCO - Partnership for Interdisciplinary Studies of Coastal Oceans
PWT - Paired Wilcoxon signed rank test
RM ANOVA - Repeated measures analysis of variance
RRMMP - Reef rescue marine monitoring program (Case Study 2)
s.e. - standard error
SIMPER - Similarity Percentage analysis
SRCC - Spearman rank correlation coefficients
SRMP - Subtidal reef monitoring program (Case Study 3)
USA - United States of America

1 Executive summary

Long-term monitoring of Marine Protected Areas (MPAs) is a requirement for successful adaptive management and global biodiversity conservation. There is now substantial scientific evidence which demonstrates the positive effects of MPAs; however some scientists have voiced their concerns about the scientific credibility of MPA monitoring. In particular the inappropriate design and statistical analysis techniques used in some MPA monitoring programmes. These scientists have questioned why MPA scientists have not made better use of the vast amount of literature which exists on good monitoring approaches in relation to marine environmental impact assessment and experimental marine ecology.

This review evaluates some key long-term MPA monitoring programmes from around the world against a good monitoring framework. This review has highlighted the following concerning issues with these monitoring programmes:

i There are very few long-term monitoring programmes (greater than five years) which have recent data presented in publicly available reports or papers - only eleven case studies were found out of over twenty MPAs (many with numerous monitoring programmes) which fit the criteria for this review.

ii All monitoring programmes fail to adequately state and link their hierarchy of key questions (MPA conservation objectives, monitoring programme objectives and hypotheses).

iii The monitoring design and data collection methods used in MPA monitoring programmes are very similar to those used in environmental impact assessment. There should be more attention paid to the discussions in this field relating to monitoring design in the naturally variable marine environment.

iv A wide variety of statistical analysis techniques are used in MPA monitoring programmes. The majority of which are scientifically valid, however most scientists fail to adequately consider the pitfalls associated with statistical inference. Greater discussion about appropriate statistical techniques is needed in the MPA literature.

v The style of reporting of MPA monitoring results varies between technical reports, scientific papers and non-technical summary reports, with most MPA monitoring results only being presented in scientific papers. Therefore MPA monitoring results are only being effectively communicated to scientific audiences.

vi Finally, the vast majority of MPA monitoring programmes are conducted by scientists independently of the agencies responsible for managing the MPAs. As a result monitoring programmes are often funded completely independently of the MPA managing agency. This observation alone can help explain some of the issues highlighted in the review, and should be addressed by MPA managing agencies.

The current issues with these monitoring programmes and lessons learned from other fields of marine and environmental research are relevant to all types of environmental monitoring. These lessons should help improve the scientific credibility and success of current and upcoming marine monitoring programmes.

2 Structure of the report

This report is presented in two volumes. Volume 1 contains the main body of the report. This includes the synthesis and analysis of the current state of long-term MPA monitoring programmes against a good monitoring framework.

For readers wishing to read only specific sections of this report:

- The Introduction, Aims and Methodology of the review can be found in sections 1-3.
- The Review of each of the case studies can be found in section 4. This goes into substantial detail of evaluating all case studies against a good monitoring framework.
- The Discussion of the results in the wider context of other fields of marine and environmental research can be found in section 5.
- The Conclusion which highlights the issues with the MPA case studies and lessons learned from other fields can be found in section 6.

Volume 2 contains Appendices 1-4. This is the background to the main report, and includes:

- Detailed summaries of each of the eleven case studies (**Appendix 1**).
- A list of other MPA monitoring programmes which were considered, but ultimately not included in the review (**Appendix 2**).
- A summary table outlining statistical analysis techniques used in marine environmental impact assessment (**Appendix 3**).
- A brief background to issues with statistical inference (**Appendix 4**).

3 Introduction

Representative networks of Marine Protected Areas (MPAs) have been rapidly established around the world in response to global commitments to biodiversity conservation in the past decade (IUCN 1994, IUCN World Parks Congress 2004). Following establishment, adaptive management of MPAs (also referred to as marine parks, reserves and sanctuaries) is required to ensure conservation, social and economic management objectives are met (Toropova *et al* 2010, Jones *et al* 2011). Biological monitoring is an imperative aspect of adaptive management, and biodiversity conservation in particular, to provide scientific evidence of the effectiveness of MPAs (Ocean Studies Board 2001, Lubchenco *et al* 2003, Pomery *et al* 2004, UNEP-WCMC 2008).

Matching the rapid rate of MPA establishment, there has been the large increase in scientific literature which demonstrates effectiveness of MPA in biodiversity conservation (see recent reviews: Garcia-Charton *et al* 2008, Lester & Halpern 2008, Lester *et al* 2009, Stewart *et al* 2009, Babcock *et al* 2010). These effects can be varied, and include: positive effects on commercially important species such as fish and invertebrates (e.g. Babcock *et al* 1999, Claudet *et al* 2006, McClanahan *et al* 2007, Barrett *et al* 2009, Babcock *et al* 2010); and both positive and negative cascading effects on other species such as invertebrates and algae (e.g. Babcock *et al* 1999, Barrett *et al* 2009, Babcock *et al* 2010). Additionally, recent research from around the world has demonstrated that MPA effects can take a long time to occur (e.g. greater than 13 years, Babcock *et al* 2010). This supports the notion that long-term monitoring programmes must be implemented and sustained to ensure successful MPA management and improvements to marine biodiversity.

Despite the growing scientific evidence demonstrating MPA effectiveness, some of this evidence is considered to be based on inappropriate monitoring design and statistical analysis (Claudet & Guidetti 2010, Stewart *et al* 2009). In fact MPA literature contains very little discussion about good monitoring approaches, particularly when compared to other fields such as environmental impact assessment (EIA) and experimental marine ecology. Many scientists have questioned why MPA science has not made better use of these good monitoring discussions (Fraschetti *et al* 2002, Guidetti 2002, Lincoln-Smith *et al* 2006, Osenberg *et al* 2006, Claudet & Guidetti 2010).

Many prominent scientists have discussed the importance of monitoring/experimental design and data analysis in relation to EIA and experimental marine ecology (Green 1979, Andrew & Mapstone 1987, Clarke & Green 1988, Clarke 1993, Underwood *et al* 2000, Kaiser *et al* 2005). More specifically these discussions have focussed on: monitoring/experimental designs which address spatial and temporal variation of the marine environment (Green 1979, Underwood 1991, 1993, Osenberg *et al* 1994, Underwood *et al* 2000, Downes *et al* 2002, Quinn & Keough 2002); and, the role of hypothesis testing and issues associated statistical inference in environmental decision making (Underwood 1997, Downes *et al* 2002, Quinn & Keough 2002). The key message from these discussions is that scientifically credible monitoring is required to make correct inferences about patterns in the marine environment.

The requirements of good monitoring/experimental design and data analysis are embodied in a “good monitoring framework”. This has been recently re-iterated by Lindenmayer & Likens (2010), who highlight that many monitoring programmes still fail to follow such a framework. A good monitoring framework involves four key steps which are considered imperative to ensure the success of a monitoring programme (adapted from Lindenmayer & Likens 2010):

1. **Key questions posed** - There must be a hierarchy of good questions posed at three levels: 1) Conservation objectives of the area being management (e.g. MPA); 2) Monitoring programme objectives; and, 3) Monitoring programme hypotheses. This stage also includes the choice of appropriate biological indicators which must be relevant to the hierarchy of questions. A hierarchy of questions can be referred to by a variety of names (e.g. Assessment Endpoint Hierarchy (three levels: Management Goals, Assessment Endpoints, and Measurement Endpoints) introduced for ecological risk assessment by Suter (1993)).
2. **Good monitoring programme design** - Monitoring design requires careful consideration of the spatial and temporal variation which operates in the system of interest. In addition, the predicted change in the biological indicator must also be considered. This is an inherently statistical process, yet statisticians are often left out of this step. This stage also includes the appropriate choice of data collection methods which address the key questions posed for the monitoring programme.
3. **Data presentation and analysis** - Appropriate data presentation and statistical analysis are required to address the hierarchy of key questions posed for the monitoring programme and managed area.
4. **Reporting of results** - Results of monitoring programmes must be interpreted and reported on a regular basis. Reporting styles can be varied in order to target different audiences (e.g. scientists, managers and members of the public). Reporting is the most important final step in a good monitoring framework which allows improved (potentially more targeted) monitoring and adaptive management.

Given the criticism of some MPA science, this report aims to review some key long-term MPA monitoring programmes from around the world. Case studies are used to evaluate whether these monitoring programmes embody the principles of a good monitoring framework. This evaluation is discussed in the wider context of environmental monitoring and experimental marine ecology where considerable attention has been paid to good monitoring approaches. The issues discussed in relation to these MPA case studies are applicable to all types of environmental monitoring. The issues and lessons learned from this review should help improve the scientific credibility and success of current and upcoming marine monitoring programmes.

4 Aim

The aim of this study is to review some of the most notable long-term marine monitoring programmes associated with Marine Protected Areas (MPAs) around the world. This review is not exhaustive. Instead, case studies are used to highlight many aspects of long-term MPA monitoring programmes, including their adherence to a good monitoring framework (outlined in the Introduction). Thus, throughout the review many comparisons are made to environmental monitoring and experimental marine ecology, where scientists have discussed at length the approaches which contribute to a good monitoring framework.

It is particularly important to assess how monitoring from MPAs is analysed and reported. This is because both independent scientists and managing agencies are often involved in MPA monitoring and there are a number of stakeholders who utilise monitoring reports (scientists, managers and members of the community). The primary resources utilised in this review therefore include both scientific publications and government reports.

This review is based on information compiled from publicly available resources and communication with primary contacts of each case study. It therefore reflects the level of external reporting for each monitoring programme. If no reporting is done, then the public perception will be that no monitoring exists. This highlights the importance of reporting monitoring results on a regular basis, and will be discussed throughout this review.

This review assumes its' readers have basic statistical and ecological knowledge. A brief summary of different statistical procedures is included in this review, and further details can be found in statistical texts (e.g. Green 1979, Sokal & Rohlf 1995, Underwood 1997, Manly 2001, Quinn & Keough 2002).

5 Methodology

5.1 Criteria for choice of case studies

This review uses case studies to highlight some of the most notable and current long-term MPA monitoring programmes around the world, and to discuss their adherence to a good monitoring framework. Case studies were chosen based on the criteria specified in **Table 1**.

Table 1. Search criteria used to determine the choice of case studies in this review.

Criteria	**Details**
Marine Protected Area	Monitoring programmes must be associated with a MPA. Monitoring occurs within (and also possibly outside of) an MPA (or network of MPAs). The primary goal of the monitoring programme must be to evaluate the effect of protection of the MPA.
Biological	Marine biological units (plant or animal species, or groups of species) are monitored (not smaller scales such as genetics or larger scales such as mapping habitats). The biological monitoring must also focus on multiple species (i.e. biological communities, not just a single species). Monitoring also must involve the visual census of species, and not estimates of species abundance based on fisheries catch data.
Current	Monitoring is current, and there must be evidence that there is an intention to continue the monitoring programme into the future, thus making it truly 'long-term'. Only recent monitoring reports/papers have been used to review each of the case studies (data and publication from 2006 onwards), in order to reflect the current approaches to monitoring (rather than historic and possibly out-dated approaches).
Scientific	Monitoring is conducted by scientists within academic institutions, government agencies or other organisations (i.e. excluding community group monitoring with the primary aim of community engagement).
English language	This review is limited to reports/papers which are written in English. If possible, Google Chrome was used to translate websites into English to find bi-lingual resources, and English versions of reports were obtained through contact with primary authors.

Initially a list of existing monitoring programmes was compiled from key MPA reviews published in the last decade[1]. This list was used to conduct a comprehensive online survey of websites, grey literature (government and other organisation reports) and peer-reviewed scientific literature to assess which monitoring programmes could be included as final case studies (based on the criteria outlined in **Table 1**).

The internet resources, Google, Google Scholar, and the ISI World of Science, where used to conduct the comprehensive online survey. The details of the monitoring programmes (MPA name, location, management agency, and authors of monitoring papers/reports) were used as search terms along with a combination of the following generic phrases to address the criteria in **Table 1**: long-term, survey, monitoring, surveillance, biodiversity, MPA, marine

[1] Key MPA reviews include: Ocean Studies Board 2001, Halpern 2003, Sobel & Dahlgren 2004, Partnership for Interdisciplinary Studies of Coastal Oceans 2007, Lester & Halpern 2008, Stewart *et al* 2008, UNEP-WCMC 2008, Wilkinson 2008, Lester *et al* 2009, Stewart *et al* 2009, Babcock *et al* 2010.

protected area, marine reserve, marine park, and marine sanctuary. The first fifty hits for each internet search were checked for relevant resources (websites and literature). These resources were also checked for links to additional resources which could be useful. Finally, contact was made with the authors of the resources to confirm that the information collected accurately represented their MPA monitoring programme.

5.2 Information collected for each case study

Standard information was collated for each of the final case studies which enabled the comparison of monitoring approaches, and included:

- General information about the MPA: MPA name, location, area, year established, conservation objectives and biological monitoring programmes conducted within the MPA.
- General information about the monitoring programme case study: Name of the monitoring programme, who conducts the monitoring and primary contact person.
- Information about the monitoring programme design: Acknowledgement of the MPA conservation objectives, monitoring programme objectives, biological element that is monitored, scale of the monitoring programme and the monitoring methods.
- Information about the data analysis and reporting: Graphical presentation and statistical analysis techniques used, results to date, reporting style and availability of reports/papers.

The final information collated for each of the case studies is provided in **Appendix 1**. All scientists and managers who are listed as primary contacts from each case study were given the opportunity to comment on the summary written and presented in **Appendix 1**.

6 Review of MPA monitoring programmes

6.1 Introduction to case studies

Over twenty MPAs (many with numerous monitoring programmes) were considered for this review. Following thorough research, only eleven long-term monitoring programmes fit the criteria for inclusion as case studies in this review (based on inclusion criteria outlined in **Table 1**).

- An introduction to each case study can be seen in **Table 2** and full details can be found in **Appendix 1**. These case studies reflect the general pattern that long-term MPA monitoring programmes are predominantly associated with MPAs which contain "no-take" zones. These no-take zones are areas closed to all fishing and extractive/damaging activities in order to provide protection to marine biodiversity. Many scientists argue that only by monitoring no-take zones that large and positive changes in marine biodiversity will occur and can be causally linked to MPA protection (compared to other MPA's which provide only partial protection) (e.g. Lester & Halpern 2008).

- The eleven case studies are considered best-practice examples of long-term MPA monitoring programmes from around the world (Australia, New Zealand, the USA and Africa). As was mentioned previously, the majority of these long-term biological monitoring programmes focussed on evaluating no-take areas within MPAs. The spatial scales of monitoring programmes is varied, with some monitoring programmes associated with large networks of MPAs (e.g. the Great Barrier Reef

MP, Australia, 34,440,000 ha; and the Florida Keys NMS, USA, 984,400 ha;**Table 2**), whilst other monitoring programmes operate on an individual park basis (e.g. CROP Marine Reserve, New Zealand, 550 ha). All of the case studies are prime examples of long-term monitoring programmes which began between the mid 1990s to early 2000s. The longest running monitoring programme reviewed here is from Tasmania's MRs which began in 1992. Many of the case studies began monitoring before MPA establishment, allowing the effectiveness of an MPA to be compared between 'before' and 'after' establishment. The four monitoring programmes which do not have 'before' data began monitoring within a few years 'after' MPA establishment.

- The majority of monitoring is conducted independently of the MPA managing agency (**Table 2**). That is, monitoring is done by scientists, either from academic institutions, government agencies or non-government organisations (NGOs) who are funded often completely independently of the MPA managing agency. In addition to this, it is often groups of scientists from different organisations which conduct monitoring in a collaborative effort (e.g. the intertidal seagrass monitoring of the Great Barrier Reef MP, kelp forest monitoring of the Channel Islands MPA network, and fish monitoring of the Florida Keys NMS). Only two monitoring programmes are contracted (and funded) to marine consultants by MPA managing agencies, and these are the for Victoria's MNPs in Australia and New Zealand's MRs (**Table 2**). Only recently has the monitoring done in Jervis Bay MP in NSW been taken on by the managing agency scientists (initially developed by independent scientists). Based on the case studies investigated here, many MPA managing agencies appear to incorporate existing scientific monitoring programmes to assist in the evaluation of their MPAs.

The remaining monitoring programmes which were considered for review, but ultimately not included are described in **Appendix 2**. The primary reasons that these were not included as case studies are:

- Long-term monitoring programmes exist but there are no recent publicly available monitoring reports/papers (e.g. there are no externally published resources from the last five years (2006 onwards));
- Long-term monitoring programmes are currently being implemented and therefore reporting has not begun; or
- No long-term monitoring is conducted (e.g. there may only be short term monitoring (<5 years) or no monitoring at all).

Table 2. Introduction to MPAs and case studies.

The description of each MPA includes an estimate of the MPA size - this relates to the MPA only, and not the additional reference sites (outside the MPA) that are often monitored. The year that monitoring began ('Monitoring initiated') is included. Monitoring programmes are highlighted as having either Before and After ($^{B/A}$) data or After only ($^{A\ only}$) data in relation to the year of MPA establishment.

MPA name	Description of MPA	Case Studies (Monitoring Programmes)	Monitoring initiated	Done by
Great Barrier Reef Marine Park (MP), Queensland, Australia	The Great Barrier Reef MP is one of the world's largest and most well known system of Marine Protected Areas (Sobel & Dahlgren 2004). Management is considered the benchmark for best practice in the world (Wilkinson 2008), with a demonstrated system of adaptive management (GBRMPA McCook *et al* 2010). The LTMP and RRMMP are considered the most comprehensive coral and seagrass monitoring program in Australia (Hirst 2008). MPA Size: **34,440,000 ha** Year established: Legislated in 1975, but not fully implemented until 1989. Major re-zoning of the park (addition of 'no-take' zones) occurred in **2004** (this is what monitoring programmes consider as the year of MPA establishment for evaluating MPA effectiveness).	1. Long Term Monitoring Program (LTMP) - coral reef benthic and fish communities	1993 $^{\mathbf{B/A}}$	Scientists: Academic/ Government
		2. Reef Rescue Marine Monitoring Program (RRMMP) - intertidal seagrass	1999 $^{\mathbf{B/A}}$	Scientists: Academic, Government, and Non-Government Organisation (NGO)
Victoria's Marine National Parks (MNPs) and Sanctuaries, Victoria, Australia	A system of MNPs and sanctuaries was established in 2002 and designed not only to maintain biodiversity, but as a representative system of protected marine environments that reflect the Victorian natural values (Sobel & Dahlgren 2004, Power & Boxshall 2007). MPA Size: 5.3 % Victoria's coastal waters (e.g. Central Victorian MNPs and Sanctuaries protect **10,813 ha**, with the single largest MNP being Port Phillip Heads MP is **3,580 ha**) Year established: **2002**	3. Subtidal Reef Monitoring Program (SRMP) - Subtidal reef benthic (invertebrates and algae) and fish communities	1998 $^{\mathbf{B/A}}$	Marine consultants
		4. Intertidal Reef Monitoring Program (IRMP) - Intertidal reef benthic communities (algae, invertebrates)	2003 $^{\mathbf{A\ only}}$	Marine consultants

MPA name	Description of MPA	Case Studies (Monitoring Programmes)	Monitoring initiated	Done by
Tasmania's Marine Reserves (MRs), Tasmania, Australia	Tasmania system of MRs were established between 1991 and 2005 in response to heavy fishing pressure and have demonstrated direct benefits of marine protection of commercially important species (Sobel & Dahlgren 2004, Barrett *et al* 2009, Babcock *et al* 2010). This is one of six MPA monitoring programmes in the world which has over a decade's worth of data which has been reported in the scientific literature (Babcock *et al* 2010). MPA Size: **2,436 ha** (Governor Island, Ninepin Point, Tinderbox, and Maria Island). Year established: **1991** (Governor Island, Ninepin Point, Tinderbox, and Maria Island).	5. Ecosystem monitoring (EM) of subtidal reef benthic communities (algae and invertebrates)	1992 **A only**	Scientists: Academic/ Government
New South Wales' Marine Parks (MPs), Australia	The NSW system of MPs was established between 1998-2005 and designed not only to maintain biodiversity, but as a representative system of marine environments in NSW (Anderson 2002, Sobel & Dahlgren 2004, NSW Marine Parks Authority 2011). MPA Size: **21,000 ha** (Jervis Bay, where long-term monitoring has been conducted). Year established: **2002** (Jervis Bay).	6. Ecosystem monitoring (EM) of subtidal reef benthic communities (algae and invertebrates)	1996 **B/A**	Scientists: Academic and Government
New Zealand Marine Reserves (MRs), New Zealand	New Zealand's system of MRs protects 0.3% of New Zealand's coastline. The oldest MR is Cape Rodney to Okakari Point Marine Reserve (CROP, also known as Leigh Marine Reserve) which was established in 1975 in response to heavy fishing pressure. This is one of six MPA monitoring programmes in the world which has over a decade's worth of data which has been reported in the scientific literature (Babcock *et al* 2010). MPA Size: **550 ha** (CROP Marine Reserve). Year established: **1975** (CROP Marine Reserve)	7. Cape Rodney to Okakari Point (CROP) Marine Reserve fish monitoring	1978 **B/A** [2]	Marine consultants

[2] CROP Marine Reserve monitoring by marine consultants began in 2000, and this is a continuation of the scientific surveys which began in 1978.

MPA name	Description of MPA	Case Studies (Monitoring Programmes)	Monitoring initiated	Done by
Channel Islands Marine Protected Area (MPA) network, California, USA	Channel Islands MPA network was established in 2003 and is the largest NMS network off the continental United States (National Oceanic and Atmospheric Administration 2011). It extends up to 3 nautical miles offshore. It incorporates the Anacapa Island Marine Reserve, which was established by the National Park Service (NPS) in 1978 (Protect Planet Ocean 2010), where the long-term (30 year) KFM programme has been conducted by the NPS (Babcock *et al* 2010, U.S. National Park Service 2010). MPA Size: **48,800 ha** Year established: **2003**	8. Kelp Forest Monitoring (KFM) program - reef and pelagic fish associated with kelp forests	1999 **B/A**	Scientists: Academic, Government and NGO
Florida Keys National Marine Sanctuary (NMS), Florida, USA	The Florida Keys NMS was established in 1990 and is one of the largest bank-barrier reef systems in the world and the largest protected coral reef system in the USA (Keller & Donahue 2006, National Oceanic and Atmospheric Administration 2007). The Florida Keys NMS also includes the relatively undisturbed and unique coral reef system, the Tortugas Ecological Reserve which has been the focus of substantial scientific research (National Oceanic and Atmospheric Administration 2007). MPA Size: **984,400 ha** (whole Florida Keys NMS), **2,930 ha** (no-take areas - the focus of the CRCP) Year established: Florida Keys NMS was established in **1990**, with no-take zones established in **1997** in the Florida Keys Reef Track east of Key West	9. Coral Reef Evaluation and Monitoring Project (CREMP) - coral reef benthic communities	1996 **A only** [3]	Scientists Academic/ Government
		10. Coral Reef Conservation Program (CRCP) - coral reef fish communities	1994 **B/A** [4]	Scientists: Academic and Government
Kenya's Marine National Parks (MNPs), Africa	Kenya's system of MNPs was established between the 1970s and 1990s (Muthiga 2006, 2009). The demonstrated effects of the Kenyan MNPs have been well published and discussed in the scientific literature (International Coral Reef Action Network 2004, McClanahan 2008a&b, Muthiga 2006, Sobel & Dahlgren 2004). This is one of six MPA monitoring programmes in the world which has over a decade's worth of data which has been reported in the scientific literature (Babcock *et al* 2010).	11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reef benthic (invertebrates and algae) and fish communities	1993 **A only**	Scientists: Academic/ NGO

[3] Related to the Florida Keys NMS establishment in1990
[4] Related to the establishment of the "no-take zones" in the Florida Keys Reef Track east of Key West in1997

MPA name	Description of MPA	Case Studies (Monitoring Programmes)	Monitoring initiated	Done by
	MPA Size: **1,800 ha** (Malindi, Watamu and Mombasa MNPs which have been the focus of long-term monitoring) Year established: **1991**			

The following review summarises the common themes, dissimilarities and novel approaches seen in the 11 case studies following the structure of the four key components of a good monitoring framework outlined in the Introduction. For full details of each case study, please see **Appendix 1**.

6.2 Key questions posed

6.2.1 Conservation objectives of MPAs

The conservation objectives all of the MPAs are very general and include statements such as “to protect/maintain/preserve biodiversity”, and “to maintain ecosystem/natural processes” (for the Australian MPAs: Victoria, Tasmania and NSW; for individual MPA conservation objectives, please see **Appendix 1**).

All monitoring programme reports/scientific papers reviewed here fail to acknowledge the overall conservation objectives for the MPA which they are monitoring (see “Acknowledgement of conservation objectives” for each case study in **Appendix 1**). Instead authors typically focus on specifying the objectives of the monitoring programme. Monitoring programme co-ordinators may simply overlook specifying the MPA conservation objectives. This may be because the conservation objectives are considered to be so general and are assumed to be clearly embodied in the original design of a monitoring programme. However the failure to explicitly link the monitoring programme objectives with the MPA conservation objectives can lead to a lack of clarity about what a monitoring programme is actually measuring and indicative of. This is particularly the case when most conservation objectives of MPAs are related to “biodiversity” which can have a range of meanings.

6.2.2 Monitoring programme objectives

The objectives of monitoring program fall into three general categories (**Table 3**). Monitoring is conducted to assess:

1. Long-term temporal trends,
2. Spatial differences, or
3. Differences between ‘no-take’ and ‘reference’ sites.

Half of the monitoring programmes explicitly aim to assess long-term temporal trends, and half of the monitoring programmes also aim to assess spatial differences between regions, locations, sites or habitats.

The most common monitoring programme objective is the aim to assess the difference between ‘no-take’ and ‘reference’ sites. In these monitoring programmes, no-take sites are those which are fully protected (closed to all fishing and extractive or damaging activities). Reference sites are used to assess the effect of the no-take sites, and are therefore located in areas of the MPA which are only partially protected (where there is only partial restriction of damaging activities) or areas outside of the MPA (where there is no restriction of damaging activities).

The only two monitoring programmes which do not assess the difference between no-take and reference sites are the Great Barrier Reef MP seagrass monitoring programme and the Florida Keys NMS coral monitoring programme. Additionally, the Great Barrier Reef MP coral monitoring programme is primarily aimed at assessing long-term temporal trends and has only recently begun monitoring fish communities between ‘no-take’ and ‘reference’ sites (using 2006 data only to date). These three monitoring programmes all focus on assessing long-term temporal trends and assessing spatial differences within the large network of MPAs which they occur in (the Great Barrier Reef MP and Florida Keys NMS).

Table 3. Monitoring programme objectives.

Case Study	Monitoring Programme Objectives. To Assess:		
	Long-term temporal trends	**Spatial differences**	**Differences between no-take and reference sites**
1. Great Barrier Reef MP, Australia - LTMP (coral reef benthic and fish communities)	✓	✓	✓
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)	✓	✓	
3. Victoria's MNPs, Australia - SRMP (subtidal reef benthic and fish communities)	✓	✓	✓
4. Victoria's MNPs, Australia - IRMP (intertidal reef benthic communities)	✓		✓
5. Tasmania's MRs, Australia - EM (subtidal reef benthic communities)			✓
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)	✓	✓	✓
7. CROP MR, New Zealand - fish communities		✓	✓
8. Channel Islands MPA network, USA - KFM (kelp forest fish communities)		✓	✓
9. Florida Keys NMS, USA - CREMP (coral reef benthic communities)	✓	✓	
10. Florida Keys NMS, USA - CRCP (coral reef fish communities)			✓
11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reef benthic and fish communities			✓

6.2.3 Hypotheses and predicted effect sizes

Nine of the monitoring programmes fail to translate their general monitoring objectives into specific hypotheses to test their monitoring data.

Only two monitoring programmes translate their general monitoring objectives into specific hypotheses to test their monitoring data. These are the fish monitoring programmes from the Channel Islands MPA network (Case Study 8) and the Florida Keys NMS (Case Study 10). Both of these monitoring programmes specify the direction of the predicted effect, by hypothesising that targeted/exploited fish species would increase in no-take areas compared to reference areas. They also hypothesise that there would be no effect of no-take areas on non-targeted fish species.

None of the monitoring programmes specify the effect size that they aim to detect with their monitoring data (e.g. the percentage difference in the abundance of a species of fish expected between 'no-take' and 'reference' areas). The lack of a specified effect size is appropriate for some monitoring programmes, as their monitoring objectives are only to assess spatial and temporal trends. However, the lack of specified effect sizes is concerning for all nine monitoring programmes which aim to assess differences between 'no-take' and reference sites.

6.2.4 Biological indicators

This review was open to including all types of marine biological monitoring (e.g. soft-substrate/hard-substrate, near-shore/off-shore, tropical/temperate) as case studies. However, some strong patterns became evident in the type of long-term monitoring programmes which are associated with MPAs around the world. Of course there are many types of monitoring programmes which can be associated with MPAs, but many of these are short term or less frequent, and therefore did not fit the criteria of inclusion for this review.

All of the case studies reviewed here are near-shore monitoring programmes, associated with shallow hard-substrate habitats (either rocky reefs or coral reefs), with the exception of the intertidal seagrass monitoring in the Great Barrier Reef MP (Case Study 2) (**Table 4**). Near-shore rocky reefs or coral reefs appear to be the most common habitats monitored within MPAs (based on Case Studies 1-11 and other MPA monitoring considered for review in **Appendix 2**). Some of the MPA's included in this review have areas of deep-water and/or off-shore protection, however ongoing long-term monitoring does not appear to occur in these areas. For example the near-shore areas of the Channel Islands MPA network (occurs from 0-3 nautical miles) is regularly monitored by scientists (case study 8); however no monitoring occurs in the Channel Islands National Marine Sanctuary (NMS) which occurs from 3-6 nautical miles. In fact NOAA (the managing agency of the Channel Islands NMS) utilises the near-shore monitoring results from the Channel Islands MPA network to assess the performance of the off-shore Channel Islands NMS (see **Appendix 1**, Case study 8 for more details).

Five monitoring programmes occur in tropical waters and the remaining six monitoring programmes occur in temperate waters. Most monitoring programmes use multiple species of fish, invertebrates and algae as biological indicators, with targeted/exploited fish and invertebrates being the focus of some monitoring programmes to assess direct effects of reserve protection, whilst benthic invertebrates and algae are the focus of other monitoring programmes to assess indirect effects of reserve protection. Only three of the monitoring programmes reviewed here exclusively use exploited/targeted and non-targeted fish species as biological indicators to assess the effects of reserve protection (CROP MR, New Zealand, Channel Islands MPA network, and Florida Keys NMS).

Table 4. Biological indicators (habitats and species) monitored.

Case Study	Habitat			Species		
	Coral reef	**Rocky reef**	**Seagrass**	**Algae**	**Invertebrates**	**Fish**
1. Great Barrier Reef MP, Australia - LTMP (coral reef benthic and fish communities)	✓			✓	✓	✓
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)			✓			
3. Victoria's MNPs, Australia - SRMP (subtidal reef benthic and fish communities)		✓		✓	✓	✓
4. Victoria's MNPs, Australia - IRMP (intertidal reef benthic communities)		✓		✓	✓	
5. Tasmania's MRs, Australia - EM (subtidal reef benthic communities)		✓		✓	✓	
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)		✓		✓	✓	✓
7. CROP MR, New Zealand - fish communities		✓ (various habitats)				✓
8. Channel Islands MPA network, USA - KFM (kelp forest fish communities)		✓ (kelp forest)				✓
9. Florida Keys NMS, USA - CREMP (coral reef benthic communities)	✓			✓	✓	
10. Florida Keys NMS, USA - CRCP (coral reef fish communities)	✓					✓
11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reef benthic and fish communities	✓			✓	✓	✓

In the reports/papers which document monitoring results, only three of the eleven monitoring programmes explicitly justify the relevance of their biological indicator at an ecosystem level and also to the monitoring programme objectives (Case Studies 2, 3 and 6; **Table 5**). These monitoring programs highlight the role of the chosen biological indicators in the marine environment and how these represent ecosystem health, biodiversity, natural processes and fishing exploitation. Often this justification is mentioned within a single sentence, but this adequately places the monitoring programme results into an ecosystem level context which allows easier interpretation of results in response to monitoring objectives and higher level MPA conservation objectives. For the remaining eight monitoring programmes which fail to justify the choice of biological indicator, it is likely that the logic in the choice of biological indicators is just assumed to be clear.

Table 5. Justification of the choice of biological indicators.

Case Study	**Justification of choice of biological indicators**
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)	Seagrass beds are highlighted as important habitats in the Great Barrier Reef MP and monitoring of seagrass beds was established to provide an indication of coastal ecosystem health (McKenzie *et al* 2010).
3. Victoria's MNPs, Australia - SRMP (subtidal reef benthic and fish communities)	Victoria's shallow reefs are highlighted as a very important component of the marine environment because of their high biological complexity, species diversity and productivity (implying their utility in being an indicator of overall biodiversity and natural processes) (Edmunds *et al* 2010a).
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)	Reef systems are generally the most heavily exploited habitats and are therefore likely to show the greatest change following protection (Barrett *et al* 2007).

The monitoring programmes which have non-technical summary reports, all link the biological measures from individual monitoring programmes to aid in the assessment of conservation objectives at higher ecosystem levels (e.g. 'biodiversity' and 'ecosystem processes'). The non-technical summary reports encountered during this review are for two MPAs: the Great Barrier Reef MP (The Great Barrier Reef Outlook Report, Great Barrier Reef Marine Park Authority 2009; which utilise the results from coral reef and seagrass monitoring) and the Channel Islands MPA network (the Channel Islands National Marine Sanctuary Condition Report, Office of National Marine Sanctuaries 2009; which utilise the results from the kelp forest fish monitoring). There has also been an MPA evaluation system developed and written as a scientific paper for Kenya's MNPs (Muthiga 2009), which links the three biological measures from the Kenya's MNP coral reef monitoring programme to three biophysical indicators that it is using to evaluate MPA effectiveness (see Case Study 11 for further details, and Muthiga 2009). The summary tables within these non-technical summary reports demonstrate how the biological indicators from individual monitoring programmes are used to inform the assessment components (e.g. Great Barrier Reef MP, **Figure 1**) which contribute to an overall understanding of conservation objectives at higher ecosystem levels.

2.4.2 Populations of species and groups of species

Assessment component	Summary	Assessment Grade: Very good	Good	Poor	Very poor
Mangroves	The Great Barrier Reef is maintaining strong mangrove biodiversity with local fluctuations, mainly along the developed coast.	●			
Seagrass	The Great Barrier Reef is maintaining seagrass biodiversity with local fluctuations in inshore waters.		●		
Macroalgae	The biodiversity of macroalgae is being maintained but there is little information about its condition.		?		
Benthic microalgae	Benthic microalgae are little studied, but they are believed to be in good condition.	?			
Corals	There are more than 500 species of corals, with localised declines in some hard corals and limited information about soft corals, sea pens and sea fans.		●		
Other invertebrates	Little is known about most non-commercial invertebrate species.	?			
Plankton and microbes	Little is known about the status of plankton or microbes on the Great Barrier Reef.	?			
Bony fish	Of the more than 1600 bony fish species, only a few are known to have locally depleted populations.		?		
Sharks and rays	There is concern about declines in populations of some of the 134 shark and ray species.			?	
Marine turtles	Five of the six species of marine turtle on the Great Barrier Reef have declined; the loggerhead, flatback and green turtle nesting populations appear to have stabilised or are now increasing.			○	
Sea snakes	There are 14 species of sea snake on the Great Barrier Reef and there are serious concerns about the status of some species.			?	
Estuarine crocodiles	Numbers of estuarine crocodiles are recovering following protection of the species.		●		
Seabirds	Twenty-two species of seabird breed on the Great Barrier Reef with serious declines in some populations.			○	
Whales	Most whales appear to be maintaining intact populations. Humpback whales are recovering strongly after being decimated by whaling.		●		
Dolphins	There is limited information about most dolphin populations; but two inshore dolphin species are known to be at risk.		?		
Populations of species and groups of species	Populations of almost all known Great Barrier Reef species or groups of species appear to be intact, but some populations such as dugongs, as well as some species of shark, seabirds and marine turtles, are known to have seriously declined, due mainly to human activities and declining environmental conditions. Many species are yet to be discovered and for many others, very little is known about their status. In time, more populations are likely to decline. Populations of some formally listed threatened species have stabilised but at very low numbers; other potentially threatened species continue to be identified.		◉		

GRADING STATEMENTS

Very good - Available evidence indicates only a few, if any, populations of a species or group of species have declined.

Good - Populations of a number of species have declined significantly.

Poor - Populations of many species have declined significantly.

Very poor - Populations of a large number of species have declined significantly.

Figure 1. Great Barrier Reef Outlook Report - Biological indicators.

This table highlights the assessment components (biological indicators) that contribute to the species aspect of the 'biodiversity' conservation objective (source: Great Barrier Reef Marine Park Authority 2009, p32).

6.3 Monitoring programme design

6.3.1 Spatial and temporal replication

All monitoring programmes reviewed here incorporate replication at different spatial scales of interest (**Table 6**). For the large networks of MPAs (e.g. Great Barrier Reef MP, Channel Islands MPA network and Florida Keys NMS), Regions/Sectors/Bioregions are incorporated to represent the largest spatial scale. Some monitoring programmes stratify their sampling effort to cover different habitats, such as different sections of continental shelf (e.g. inshore middle reef and outer shelf, for the Great Barrier Reef LTMP), habitats (e.g. patch reef, shallow reef, deep reef, for the Florida Keys NMS coral reef monitoring) and water column depths (e.g. benthic, midwater and canopy level water depths, for the Channel Islands MPA network fish monitoring).

- The majority of monitoring programmes incorporate MPA (e.g. no-take) and Reference locations; however the Great Barrier Reef MP seagrass and coral reef (LTMP) monitoring and the Florida Keys NMS coral reef monitoring programmes do not monitor Reference locations[5]. Instead, they only monitor within their large networks of MPAs which contain partial protection from destructive activities (Great Barrier Reef MP: 34,440,000 Ha, Florida Keys NMS: 984,400 Ha; **Table 2**). These three monitoring programmes are designed to monitor temporal and spatial trends only, and not to evaluate the effectiveness of their MPA (as discussed in section 6.2.2, **Table 3**), therefore Reference sites are not required.

- All monitoring programmes incorporate Locations, with multiple Sites and generally multiple sampling units (e.g. transects/quadrats) to incorporate the smaller scales of spatial variability. Only three monitoring programs have insufficient replication within Sites (only one transect at each site), and these are all subtidal reef monitoring programs from Victoria, NSW and Tasmania. All of these programs have stemmed from the one method developed by Edgar & Barrett (1997).

- The sampling units for each monitoring programme are generally fixed transect/quadrats which have been repeatedly surveyed through time, while only four monitoring programmes state that their sampling units are randomly/haphazardly positioned within Sites (**Table 6**). Most Locations and Sites are assumed to be fixed (nb: most monitoring programmes rarely state this, it is only clear when factors are declared to be the opposite of fixed (i.e. random) for ANOVA tests).

- Only two monitoring programmes have Sites designated as random factors: the coral reef monitoring in Florida Keys NMS and the fish monitoring at CROP MR in New Zealand (**Table 6**). The fish monitoring at CROP MR explained that Sites are treated as a random factor, as Sites were initially selected from a randomised block design. These 'random' Sites have since been repeatedly surveyed through time (Haggitt *et al* 2008). This does have implications for data analysis (e.g. a Repeated Measures ANOVA should be used rather than a straightforward ANOVA - for further details see the Discussion, section 7.3)

- All monitoring programmes are ongoing and long-term (running for longer than five years). The temporal replication of monitoring programmes varies from twice a year (Great Barrier Reef MP seagrass monitoring, capturing seasonal variation) to up to once every three years (Victoria's MNPs subtidal reef monitoring). The initial

[5] with the exception of a small monitoring programme within the Great Barrier Reef MP LTMP which is designed to assess the effect of no-take vs reference zones.

frequency of all monitoring programmes is annual monitoring; however in some cases the sampling frequency has been scaled back as the monitoring programme has progressed. This is particularly for the monitoring done by contractors: Victoria's MNPs subtidal and intertidal reef monitoring and CROP MR New Zealand fish monitoring.

- As was discussed in section 6.1(**Table 2**), many of the monitoring programmes began before the establishment of the MPAs, giving crucial 'before' data to compare the effectiveness of the MPAs to 'after' establishment data. However, five of the monitoring programmes began between one and two years 'after' MPA establishment (Victoria's MNPs, Australia (IRMP); Tasmania's MRs, Australia; CROP MR, New Zealand; Florida Keys NMS, USA; and, Kenya's MNPs, Africa; **Table 6**).

Table 6. Spatial and temporal replication of monitoring programmes.

Monitoring programmes are highlighted as having either Before and After ([B/A]) data or After only ([A only]) data in relation to the year of MPA establishment.

Case Study	Spatial Replication	Temporal Replication
1. Great Barrier Reef MP, Australia - LTMP (coral reef benthic and fish communities)	Sectors (within MPA only; no control) • three sections of Continental shelf • multiple Reefs • multiple Sites • multiple Transects (fixed)	Annual (different reefs on a bi-annual basis), 1993-2007 [B/A]
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)	Sectors (within MPA only; no control) • multiple Locations • two Sites • three Transects (fixed) • up to 11 Quadrats (no control)	Bi-annual, 1999-2010 [B/A]
3. Victoria's MNPs, Australia - SRMP (subtidal reef benthic and fish communities)	MPA/Reference locations • multiple reef Sites • One Transect (fixed)	Currently every 2-3 years, 1998-2009 [B/A]
4. Victoria's MNPs, Australia - IRMP (intertidal reef benthic communities)	MPA/Reference locations • Transects (fixed) • five Quadrats	Currently every 1-2 years, 2003-2009 [A only]
5. Tasmania's MRs, Australia - EM (subtidal reef benthic communities) [6]	MPA/Reference locations • multiple reef Sites • One Transect (fixed)	Currently annual, 1992-2002 [A only]
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)	MPA/Reference locations • multiple reef Sites • One Transect (fixed)	Repeat surveys from 1996-2007 [B/A]
7. CROP MR, New Zealand - fish communities	MPA/Reference locations • multiple Sites (randomly allocated initially, but repeatedly surveyed through time) • 10 Transects (random)	Currently every 1-3 years since 2000-2008 [B/A] [7]
8. Channel Islands MPA network, USA - KFM (kelp forest fish communities)	Bioregions • MPA/Reference locations • multiple Sites • Three water Depths • multiple Transects (random)	Annual, 1999-2008 [B/A]
9. Florida Keys NMS, USA - CREMP (coral reef benthic communities)	Regions (within MPA only; no control) • Sites (randomly allocated initially, but repeatedly surveyed through time) • four Habitat types • multiple Stations (fixed)	Annual, 1996-2008 [A only]
10. Florida Keys NMS, USA - CRCP (coral reef fish communities)	MPA/Reference locations • multiple Sites • four Habitat types • multiple 7.5m radius circular Plots (random)	Annual, 1994-2007 [B/A]

[6] The Ecosystem Monitoring of Tasmania's MRs is the longest running temperate MPA monitoring programme in Australia. The most recent paper from this (Barrett et al 2009) only presents data up to 2002. Although this is older than what was required by the review criteria (Table 1), this case study was considered very important to include in this review.
[7] CROP Marine Reserve monitoring by marine consultants began in 2000, and this is a continuation of the scientific surveys which began in 1978.

Case Study	Spatial Replication	Temporal Replication
11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reed benthic and fish communities	MPA/Reference locations • multiple Sites • multiple Transects (random)	Annual, 1993-2005 [A only]

The majority of monitoring programmes involve visual census of biological units (Table 7). Only two monitoring programmes (Great Barrier Reef MP and Florida Keys NMS coral reef monitoring programmes) analyse stills or video footage (collected by divers) in a lab/office to estimate biological units along their transects (for further details see **Appendix 1** Case Studies 1 and 9).

Table 7. Data collection methods**.**

Case Study	Visual census	Stills/Video footage
1. Great Barrier Reef MP, Australia - LTMP (coral reef benthic and fish communities)		✓
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)	✓	
3. Victoria’s MNPs, Australia - SRMP (subtidal reef benthic and fish communities)	✓	
4. Victoria’s MNPs, Australia - IRMP (intertidal reef benthic communities)	✓	
5. Tasmania’s MRs, Australia - EM (subtidal reef benthic communities)	✓	
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)	✓	
7. CROP MR, New Zealand - fish communities	✓	
8. Channel Islands MPA network, USA - KFM (kelp forest fish communities)	✓	
9. Florida Keys NMS, USA - CREMP (coral reef benthic communities)	✓	✓
10. Florida Keys NMS, USA - CRCP (coral reef fish communities)	✓	
11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reef benthic and fish communities	✓	

6.4 Data analysis and presentation

A number of univariate and multivariate graphical presentation and statistical analysis techniques are used to convey information about data collected within each monitoring programme (**Table 8**). The nature of these techniques, in terms of presenting or analysing spatial (S) or temporal (T) data, is described in **Table 8**.

The vast majority of graphical presentation and statistical analysis techniques are univariate techniques (for single biological response variables; **Table 8**), and interestingly very few monitoring programmes shared approaches to data presentation and analysis.

The following sections outline the ways in which biological data from each case study has been presented and analysed.

6.4.1 Presentation and analysis of results over time

The most common graphical presentation technique that all monitoring programmes use is the presentation of univariate data (e.g. abundance/cover/biomass/diversity) in the form of temporal plots (data plotted through time; **Table 8**). The approach to plotting data through time varies between monitoring programmes, and falls into one of four categories: time-series plots, scatter plots, bar graphs or box plots (**Figure 2**). Those case studies which are highlighted in section 6.3.1 as only monitoring within their MPA (i.e. no Reference locations), plot their data through time either at the MPA level (e.g. **Figure 2d**, coral species abundance over time within the Florida Key NMS) or grouped within regions and habitat types (e.g. Figure 2b, Great Barrier Reef MP coral reef monitoring). All other monitoring programmes which monitor MPA and Reference sites plot their data over time for these separate areas (e.g. **Figure 2a** fish abundance of no-take and fished areas from Florida Key NMS, and **Figure 2c** fish abundance between Take and No Take sites from Jervis Bay MP).

Four of the monitoring programmes only use graphical presentation of plots of temporal trends to demonstrate biological changes through time, with temporal trends being summarised as positive, negative or no trend (Case Studies 3, 4, 7 and 11; **Table 8**). The remaining seven monitoring programmes use various types of statistical analysis techniques to support the graphical presentation of temporal trends. The statistical analyses are used to do one of two things: 1) to define the form of temporal trends, or 2) to evaluate differences in temporal trends between MPA and References sites.

a Techniques to assess the form of temporal trends

The statistical analysis techniques used to assess the form of temporal trends are all used to summarise temporal trends in terms of positive, negative or no trend. The statistics used to test the form of temporal trends include:

- **Linear mixed effect models** (LMEM; used by the Great Barrier Reef MP coral reef monitoring programme, Case Study 1; see **Figure 2b** by fitting LMEM to coral and fish data for each Sector and subregion (e.g. Cairns Sector, inshore subregion), Sweatman *et al* (2008) determine the form of temporal trend (no trend, linear, quadratic, or smooth (non linear) trend) and direction of change over time (positive, negative or no trend through time). LMEM is very similar to ANOVA (see below; response variable must have a Normal distribution and factors can be fixed and random), but the focus of LMEM is to determine the form of the 'fixed-effect' relationship (which in this case is the form of the relationship between survey year and the biological response variable). Results from the LMEM are summarised for each Sector across the Great Barrier Reef MP and presented in a visual summary, where the overall (average) trend (over 13 annual surveys) and the current trend (between the two latest surveys) of different biological groups is summarised (increasing, no change, decreasing; **Figure 3**).

- **Generalized mixed model regression** (GMMR; used by the Florida Keys NMS coral reef monitoring programme, Case Study 9; Ruzicka *et al* 2010). GMMR is used to assess long-term trends in species richness and % cover of benthic coral reef species within regions and habitats in the Florida Keys NMS. Temporal trends are plotted through time, with significant trends highlighted in time-series plots, and a summary of the direction of trends (increasing, decreasing or no change) is provided in table format (**Figure 4**).

- **Analysis of variance** (ANOVA; used by the Great Barrier Reef MP seagrass monitoring programme, Case Study 2; McKenzie *et al* 2010). ANOVA is used to assess whether there is a significant change over time in seagrass abundance at the high spatial level of the entire Great Barrier Reef MP (McKenzie *et al* 2010). By using ANOVA, McKenzie *et al* (2010) revealed a significant decline in seagrass abundance over the monitoring period from 1999-2010 at the Great Barrier Reef MP.

- **Repeated measures analysis of variance** (RM ANOVA) is only used by the Florida Keys NMS coral reef monitoring programme (Case Study 9; Ruzicka *et al* 2010) to assess significant differences between groups (based on Region and Habitat) between years. RM ANOVA is used because the sampling units in this monitoring programme are fixed (repeatedly sampled through time, therefore sampling time is considered non-independent; Green, 1993). Post-hoc Tukey tests are used to identify significant differences between years (as denoted by the letters presented above the boxplot shown in **Figure 2d**).

b Techniques to evaluate differences in temporal trends between MPA and References sites

There are a number of different statistical analysis techniques used to evaluate differences in temporal trends between MPA and References sites, and these include:

- **Spearman rank correlation coefficients** (SRCC; used by the Tasmanian MR subtidal reef monitoring programme, Case Study 5, Barrett *et al* 2009). SRCC are used to assess the significance (based on two-tailed critical values) of serial convergence or divergence between Reserve and Fished areas over time. Barrett *et al* (2009) detected some trends between reserves and fished areas, but many of these were species and site specific.

- **Repeated measures analysis of variance** (RM ANOVA; used by the Jervis Bay subtidal reef monitoring programme, Case Study 6, Barrett *et al* 2007). RM ANOVA is used because the sampling units in this monitoring programme are fixed (repeatedly sampled through time, therefore sampling time is considered non-independent). RM ANOVA is used to assess differences between management zone (Take and No Take) and years which support the graphical presentation of data in bar graphs (**Figure 2c).** The RM ANOVA used by Barrett *et al* (2007) detected very few effects of management zone over the sampling period (1998, 2003-2007), but this was thought to be because no-take zones had only existed for 4.5 years and a more realistic and biologically relevant time-frame to detect change would be between 5-10 years after establishment of a no take zone (Barrett *et al* 2007).

- **Analysis of co-variance** (ANCOVA; used by the Channel Islands MPA network fish monitoring programme, Case Study 8, Hamilton *et al* 2010). ANCOVA is used in a very similar way to RM ANOVA, but instead of treating time as a fixed factor it is treated as a random co-variate. ANCOVA is used by Hamilton *et al* (2010) to assess the difference between reserve and non-reserve groups of sites over time. Hamilton *et al* (2010) found a significant effect of time and reserve (significant interaction) on targeted fish biomass, where biomass trajectories were inside and outside of the reserves diverged through time (as presented in a scatter plot, **Figure 5**). NB: The use of ANCOVA by Hamilton *et al* (2010) is insufficiently explained and is considered inappropriate given the characteristics of the data they were using - RM ANOVA would have been more appropriate.

- **Confidence Intervals** (CIs, used by Florida Keys NMS fish monitoring programme, Case Study 10, Bohnsack *et al* 2009, **Figure 2a**). 95% CIs are used to assess the difference between annual mean abundance of targeted or non-targeted fish species in reserves or fished areas compared to baseline conditions. Baseline conditions for targeted and non-targeted fish species were determined from monitoring data collected prior to reserve establishment (1994-1997). The baseline conditions (for reserves or fished areas) are compared to the 95% CIs of the abundance of fish (for reserves or fished areas) for each year of data. Data is plotted on a time-series graph for each species, along with baseline conditions for reserves or fished areas and asterisks above any time where there is a significant difference between reserves or fished areas (95% CIs) and baseline condition (**Figure 2a**). Bohnsack *et al* (2009) explicitly state their hypotheses about the fish species that were monitored. They hypothesised: “the abundance of exploited species should increase in no-take reserves because of relaxed fishing pressure compared to similar habitat in fished areas subjected to fishing. Reference species not directly targeted by fishing are not predicted to increase directly in response to relaxed fishing pressure”. The use of 95% CI as an alternative to statistical significance tests is considered more intuitive by some (e.g. Fidler *et al* 2006), and in this case certainly allowed Bohnsack *et al* (2009) to make a strong conclusive statement confirming all hypotheses were validated by the data and analyses.

SIMPER (Similarity Percentage analysis; used by the Tasmanian MR subtidal reef monitoring programme, Case Study 5, Barrett *et al* 2009). SIMPER is the only multivariate analysis technique used to evaluate the differences between MPA and Reference sites over time, and it was also only used on one occasion by Barrett *et al* (2009) out of all of the monitoring programmes reviewed here. SIMPER is used to support the graphical presentation of multivariate data (using a non-metric Multi Dimensional (MDS) plot; **Figure 6**)

- **Figure 6** to determine influential species which contribute to differences between reserves and fished areas.

There are two other less common ways which differences in temporal trends between MPA and References sites have been presented using graphical techniques, and these are:

- **Size-frequency distributions** (or abundance of different size classes) of targeted species are used in three monitoring programmes (**Table 8**, Victoria’s MNP, Jervis Bay MP and the Tasmanian MR subtidal reef monitoring programmes; e.g. **Figure 7**). These visually demonstrate the effect of MPAs vs Reference sites on the size of commonly fished/exploited species over time (with the idea that larger individuals occur at greater abundance within MPAs as time since establishment increases). No statistical analysis is used to support these types of graphical presentation of results.

- **Non-metric Multi Dimensional** (MDS) plots are used in four monitoring programmes to graphically present assemblage level data grouped in MPAs vs Reference sites over time (Table 8, Victoria’s MNP subtidal and intertidal reef monitoring programme and the Jervis Bay MP and Tasmanian MR subtidal reef monitoring programmes, e.g. **Figure 6** and **Figure 8**). Only once was an MDS plot supported with statistical analysis (SIMPER used by Tasmanian MR subtidal reef monitoring programme, Case Study 5, Barrett *et al* 2009). All other times MDS plots are simply used as a graphical presentation technique to show how assemblages differed between MPAs vs Reference sites over time. The utility of such plots is questionable when many data points are presented and interpretation of possible patterns may vary between scientists (e.g. **Figure 8**).

Table 8. Univariate and multivariate graphical presentation techniques and statistical analysis techniques used for each monitoring programme.

The nature of these techniques, in terms of the type of data analysed/presented is denoted by an S or T, for spatial (e.g. Region, Habitat, Site) or temporal (e.g. Year) analysis/presentation respectively. Case studies which use statistical analysis techniques to formally test temporal trends are highlighted in blue, and case studies which use statistical analysis techniques to evaluate differences in temporal trends between MPA and References sites are highlighted in yellow.

	Graphical presentation techniques			**Statistical analysis techniques**		
	Univariate		**Multivariate**	**Univariate**		**Multivariate**
Case Study	**Temporal /spatial plots**	**Size vs frequency/ abundance**		**ANOVA**	**Other**	
1. Great Barrier Reef MP, Australia - LTMP (coral reef benthic and fish communities)	T&S				T: LMEM	
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)	T			T		
3. Victoria's MNPs, Australia - SRMP (subtidal reef benthic and fish communities)	T	T&S	S&T: MDS			
4. Victoria's MNPs, Australia - IRMP (intertidal reef benthic communities)	T		S&T: MDS			
5. Tasmania's MRs, Australia - EM (subtidal reef benthic communities)	T	T&S	S&T: MDS		T: SRCC	S&T: SIMPER
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)	T	T&S	S&T: MDS	S&T: RM ANOVA		
7. CROP MR, New Zealand - fish communities	T&S	S	S: PCA and CAP	S	S: PWT	S: PERMANOVA PCA and CAP
8. Channel Islands MPA network, USA - KFM (kelp forest fish communities)	T&S		S: MDS	S	S&T: ANCOVA	
9. Florida Keys NMS, USA - CREMP (coral reef benthic communities)	T			S&T: RM ANOVA	T: GMMR	
10. Florida Keys NMS, USA - CRCP (coral reef fish communities)	T				S&T: 95% CI	
11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reef benthic and fish communities	T					

ANOVA - Analysis of variance, used to test differences between groups/treatments, in these case studies factors are commonly related to space (e.g. Region, Habitat, Site) or time (e.g. year).
ANCOVA - Analysis of co-variance, used to test differences between factors with a covariate (such as time).
CAP - Canonical Analysis of Principal coordinates, used as a constrained ordination technique for testing hypotheses about factors based on multivariate (assemblage/community level) data.
CI - Confidence Intervals, used as an alternative to statistical significance tests (considered more intuitive).
GMMR - Generalized mixed model regression, used to test the form temporal trends.
LMEM - Linear Mixed Effect Models, used to test the form of temporal trends.
MDS - non-metric Multi Dimensional Scaling plots, used as a multivariate ordination technique to visualise multivariate data in generally 2-3 dimensions (often used to investigate factors such as Space and Time).
PCA - Principal coordinate analysis, used as a multivariate ordination technique to visualise multivariate data in two dimensions (often used to investigate environmental factors which influence multivariate assemblages).
PERMANOVA - Permutation analysis of variance, used like ANOVA for univariate measures, however PEMANOVA is used to test differences in factors based on multivariate (assemblage/community level) data.
PWT - Paired Wilcoxon signed rank test, used to test differences between size frequency distributions.
RM ANOVA - Repeated measures analysis of variance, used in the same way as ANOVA is, but with a fixed factor (such as site) which is repeatedly measured through time.
SIMPER - Similarity Percentage analysis, used to determine influential species (from multivariate assemblages) which contribute to differences between factors (e.g. Time and Space).
SRCC - Spearman rank correlation coefficients, used to test for convergence or divergence between temporal plots of univariate data

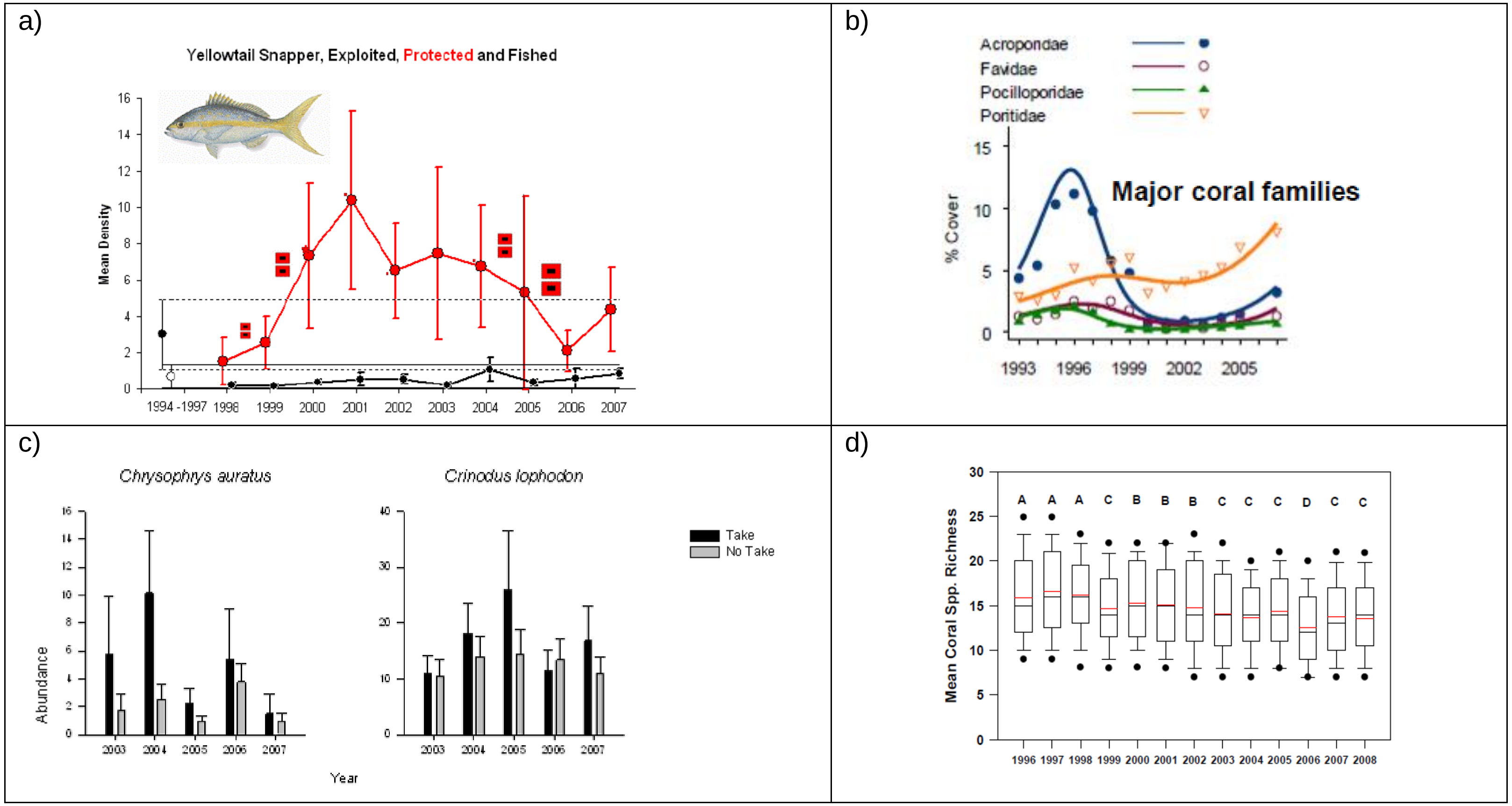

Figure 2. Examples of different approaches to plotting data through time

a) time-series of mean (with 95% confidence intervals) fish abundance in no-take (red line) and fished (black line) areas from Florida Key NMS (source: Bohnsack *et al* 2009 p21). b) scatter plot of mean coral cover from the Great Barrier Reef MP over time with fitted linear mixed effect models (Source: Sweatman *et al* 2008, p30). c) bar graph of mean (± s.e) fish abundance over time between Take and No Take sites from Jervis Bay MP (Source: Barrett *et al* 2007, p32). d) box plot of coral species richness over time from Florida Key NMS with letters above bars representing significant differences between years (source: Ruzicka *et al* 2010, p 19).

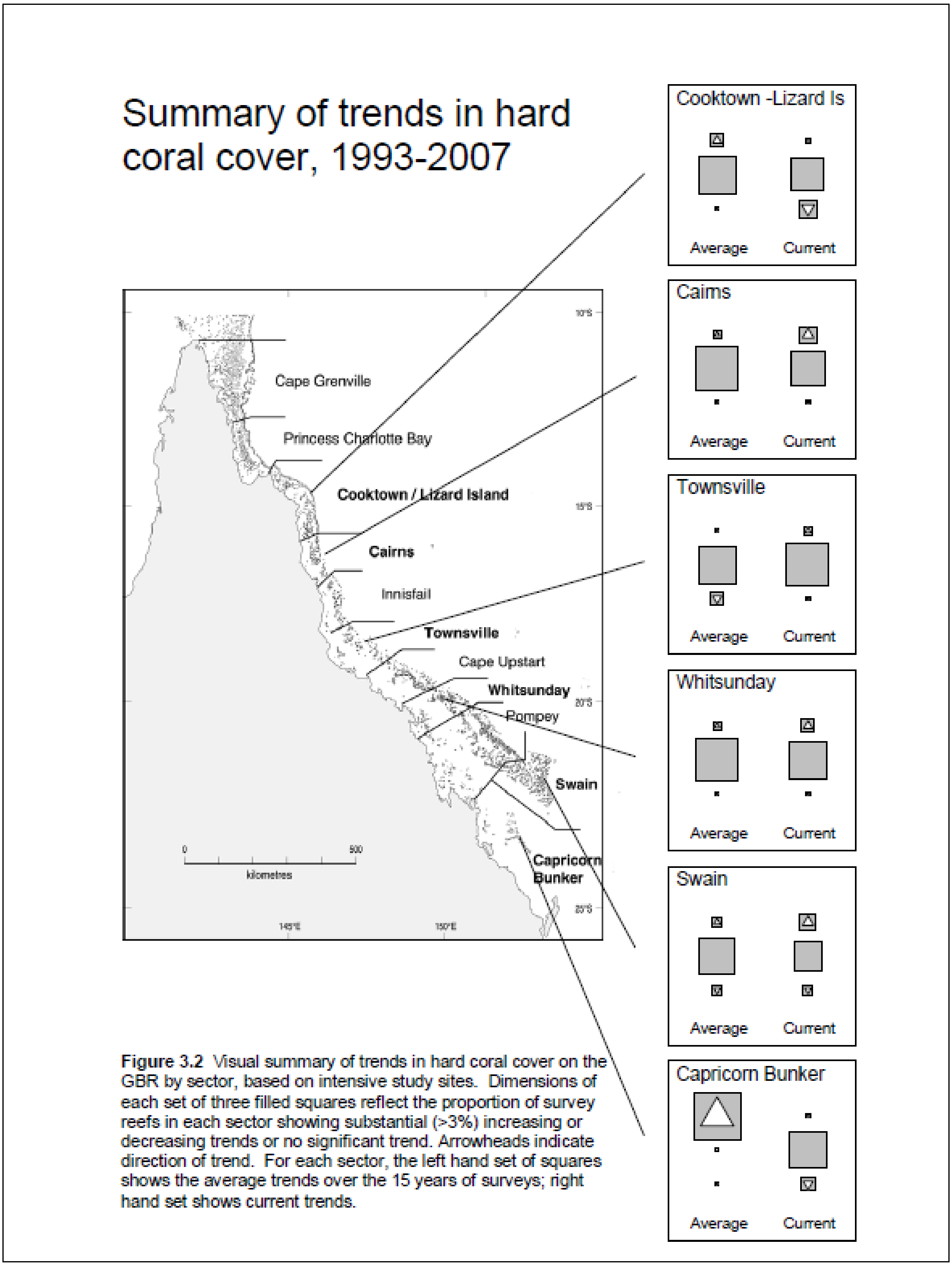

Figure 3. Visual summary of temporal trends in coral cover (based on LMEM trends) used by the Great Barrier Reef MP coral reef LTMP (Source: Sweatman *et al* 2008, p16).

a)

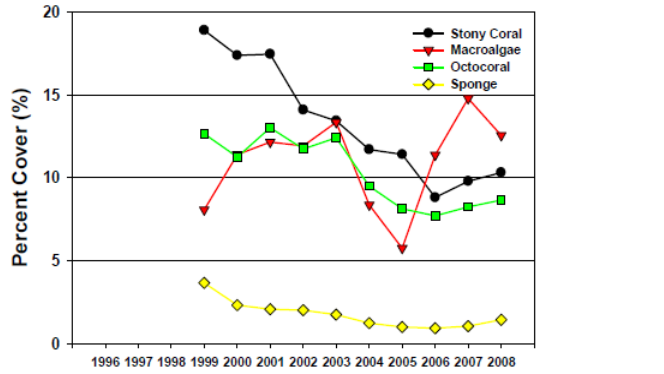

Figure 13. Mean annual percent cover for the four major benthic taxa recorded in CREMP image analysis. Mean percent cover is pooled from 12 stations in the Dry Tortugas. A mixed model regression indicates a decreasing trend for stony corals, octocorals, and sponges ($p<0.001$) and no trend for macroalgae ($p>0.05$).

b)

Table 2. Long-term trends of the four major benthic taxa recorded in CREMP image analysis. Trends were determined for 10 region*habitat groupings from a mixed model regression between 1996 and 2008. Interpretation of trends for each region*habitat grouping are based on Bonferroni corrected p values for repeated testing (adjusted $p\leq0.004$).

Reg*Hab	Stony Corals	Macroalgae	Octocorals	Sponges
LK BCP	decreasing	increasing	no change	no change
LK OD	decreasing	decreasing	no change	no change
LK OS	decreasing	no change	increasing	decreasing
LK P	decreasing	no change	increasing	no change
MK OD	decreasing	no change	no change	no change
MK OS	decreasing	no change	increasing	decreasing
MK P	no change	no change	no change	decreasing
UK OD	decreasing	no change	increasing	no change
UK OS	decreasing	no change	increasing	decreasing
UK P	decreasing	no change	no change	no change

Figure 4. The graphical and tabular presentation of temporal trends (based on mixed model regression) in cover of benthic coral reef species in the Florida Keys NMS (source: Ruzicka *et al* 2010, p 27).

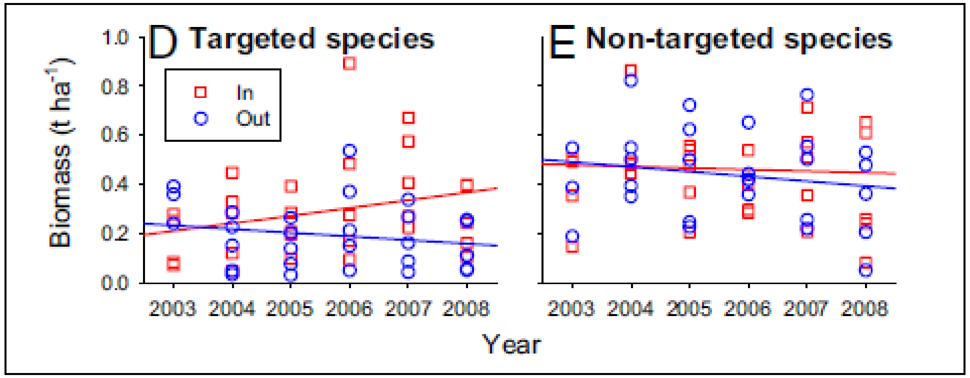

Figure 5. Scatter plots showing temporal trends in targeted and non-targeted fish biomass between Reserve (In or Out) from the Channel Islands MPA network fish monitoring programme (Source Hamilton *et al* 2010, p3).

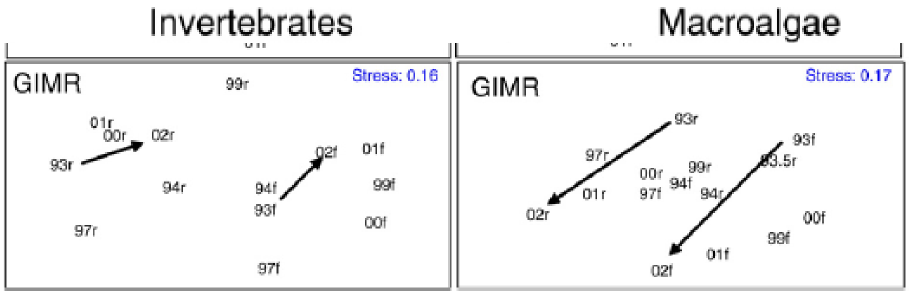

Fig. 14. MDS plots of the similarity between mobile invertebrate and macroalgal assemblages present during autumn within the Maria I (MINP), Tinderbox (TMR), Ninepin Point (NPMR) and Governor I (GIMR) marine reserves and at their respective fished reference sites between 1992 and 2002. Reserve assemblages are denoted by the suffix 'r', fished assemblages by 'f'. Arrows depict overall differences between initial and final assemblages.

Figure 6. MDS plot used to demonstrate the change in assemblages through time between reserves and fished areas from the Tasmanian MR subtidal reef monitoring programme (source: Barrett *et al* 2009, p115).

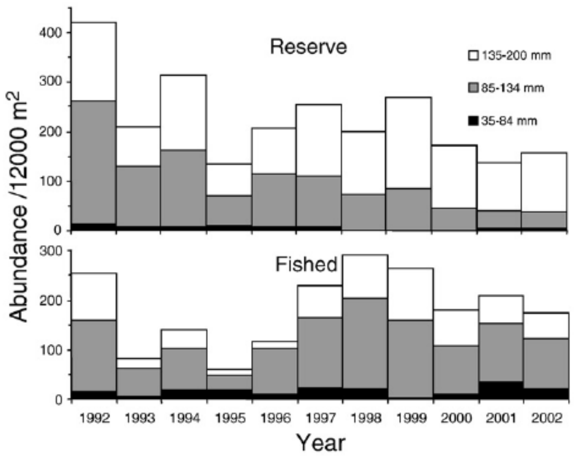

Fig. 6. Abundance per size category (shell length) of *Haliotis rubra* within the Maria I Marine Reserve and at fished reference sites between 1992 and 2002. The minimum legal size for abalone was 132 mm shell length.

Figure 7. Abundance of different size classes of the commonly exploited abalone plotted over time from the Tasmanian MR subtidal reef monitoring programme (source: Barrett *et al* 2009, p 110).

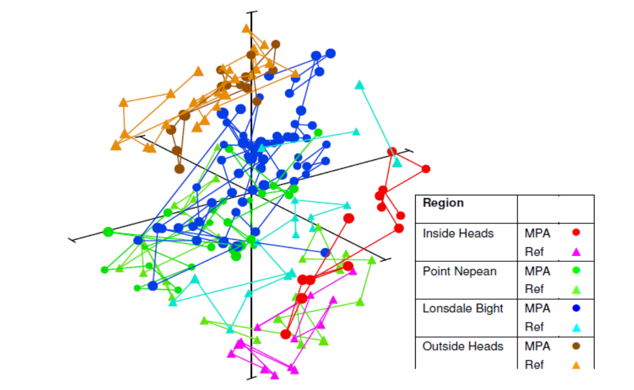

Figure 3.1. Three-dimensional MDS plot of algal assemblage structure for all Port Phillip Heads sites. Kruskal Stress value = 0.16.

Figure 8. MDS plot of algal assemblage structure for Regions and MPA or Reference sites over time from the Victorian MNP subtidal reef monitoring programme (Source: Edmunds *et al* 2010a, p22).

6.4.2 Presentation and analysis of results over space

The presentation and analysis of data over space generally occurred less in all monitoring programmes compared to the presentation and analysis of data over time (**Table 8**). This is expected given that all monitoring programmes focussed on presenting the long-term temporal changes in marine biological data in response to MPA establishment. The only two major exceptions to this, are for the CROP MR fish monitoring programme in New Zealand (Case Study 7, Haggitt *et al* 2008) and the Channel Islands MPA network fish monitoring programme (Case Study 8, Hamilton *et al* 2010).

In the case of the CROP MR fish monitoring programme, there is a focus on presenting results from the latest survey of the long-term monitoring program and assessing the spatial differences in fish between reserve versus non-reserve sites. Many of the presentation and analysis techniques are multivariate, based on fish assemblage data (e.g. the ordination techniques Canonical Analysis of Principal coordinates (CAP) and Principal Coordinate Analysis (PCA), and Permutation analysis of variance (PERMANOVA) the hypothesis test for multivariate data (similar to ANOVA)).

In the case of Channel Islands MPA network fish monitoring programme, the six years of data (2003-2008) is averaged to highlight primarily spatial differences between reserve versus non-reserve sites. Unlike the CROP MR fish monitoring programme, many of the presentation and analysis techniques are univariate (e.g. bar graphs supported by ANOVA).

6.4.3 Noteworthy examples for the presentation of the effect of MPAs

Through reviewing the presentation and analysis techniques from each of the case studies, two unique approaches (compared to the more traditional analysis and presentation techniques highlighted in 3.3.1 and 3.3.2) have been encountered which provide very clear graphical presentation of data and allow for ease of interpretation about the effectiveness of MPAs. These two noteworthy examples are:

Average Response Ratio (ARR; Channel Islands MPA network fish monitoring programme, Case Study 8, Hamilton *et al* 2010, **Figure 9**). The ARR is calculated for targeted and non-targeted fish species and is based on the average response (density or biomass) of particular species to sites inside reserves vs. sites outside reserves in a given year. The average ARR (± s.e.) is presented for the years 2005-2008, and effectively illustrates with positive (ARR >1) and negative (ARR <1) effects of the Channel Islands reserves on both targeted and non-targeted fish species. As can be seen in **Figure 9**, the density of targeted fish species is often higher in reserves, and fewer non-targeted species show a positive response to reserves (as would be expected, given there is less fishing pressure on these species outside of reserves).

Change in the presence/absence of coral species (Florida Keys NMS coral reef monitoring programme, Case Study 9, Ruzicka *et al* 2010, **Figure 10**). The change in the presence/absence of coral species is based on the gain or loss of coral species from survey stations over the duration of the monitoring programme (1996-2008). As can be seen in **Figure 10**, this graphical presentation clearly shows the substantial decline in the presence of coral species from stations within the Florida Keys NMS.

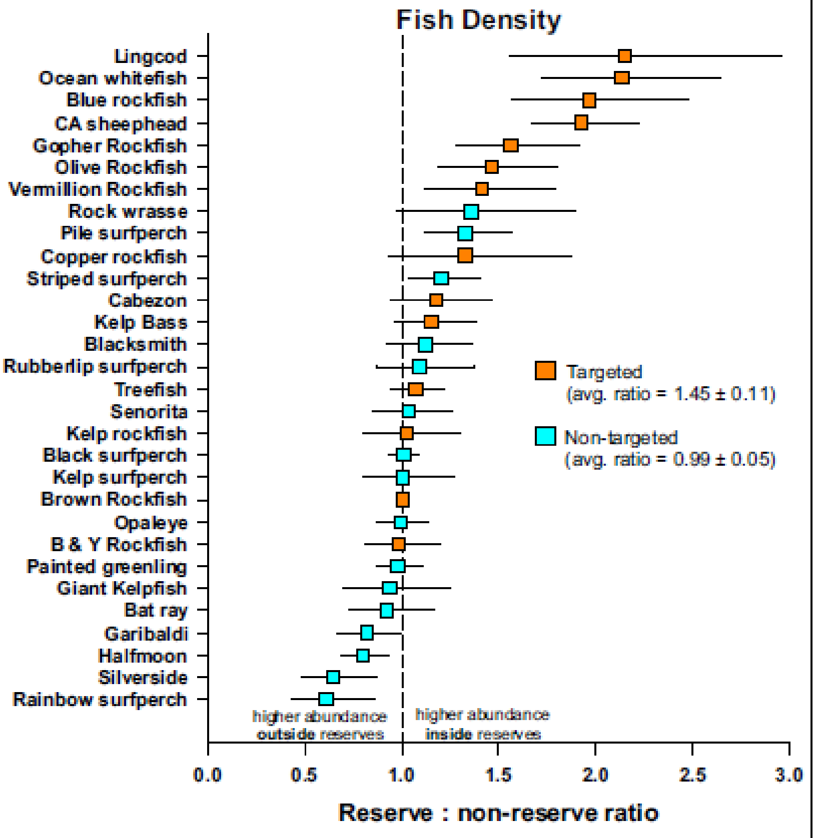

Fig. 4. ARRs (density inside/density outside) for individual targeted and nontargeted species of fish in the Channel Islands reserve network. Values represent the back-transformed average of the log response ratios for each island. Error bars are ± SE.

Figure 9. Average Response Ratio (ARR) for targeted and non-targeted fish species to demonstrate the Reserve:non-reserve ratio from the Channel Islands MPA network fish monitoring programme (Source Hamilton *et al* 2010, p3).

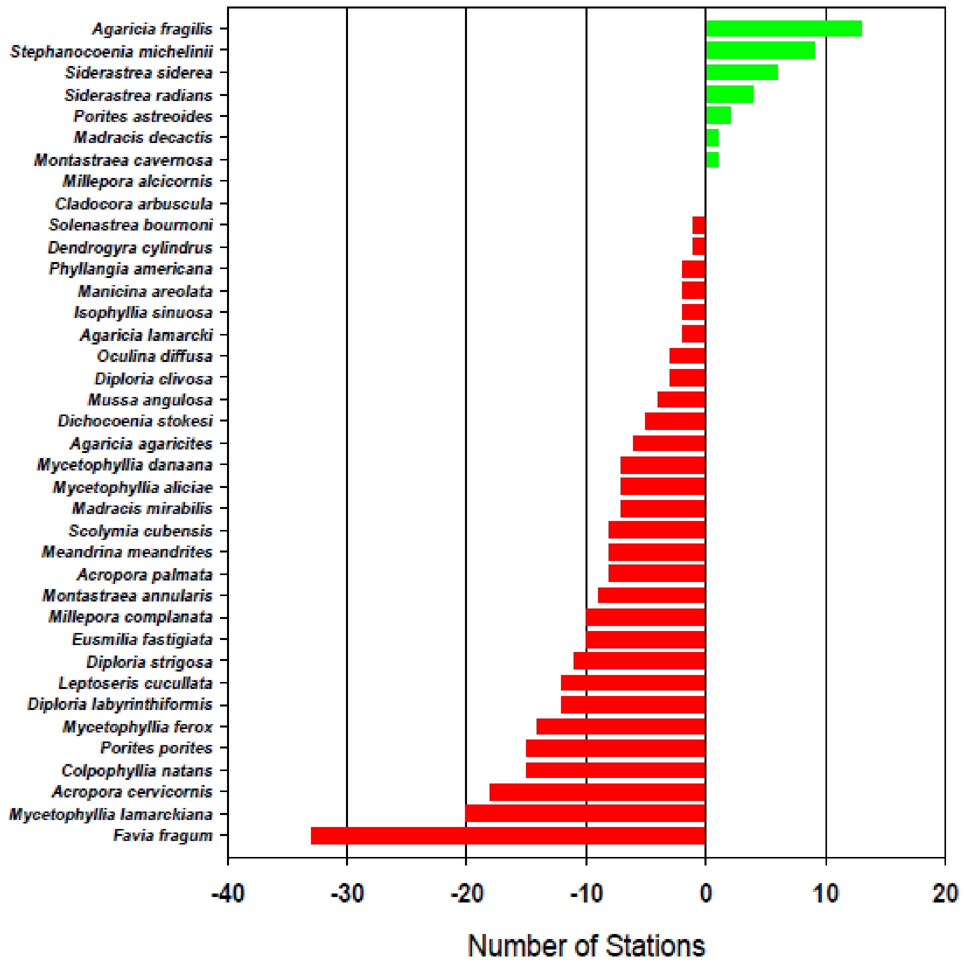

Figure 9. Change in the presence/absence (number of stations) of individual coral species from 1996 to 2008 in the Florida Keys (N=97 stations).

Figure 10. Graphical presentation of the loss or presence of coral species from stations from the Florida Keys NMS coral reef monitoring programme (source: Ruzicka *et al* 2010, p 22).

6.5 Reporting of results

In this review it was important to assess how MPA monitoring results are reported, as very different parties can be involved in monitoring activities (e.g. independent scientists and managing agencies), and results can be written for very different audiences (e.g. scientists, managers and the general public). The results of each long-term monitoring programme reviewed here are presented in four different reporting styles: technical reports, scientific (peer reviewed) papers, reviews, or non-technical summary reports (**Table 9**).

The majority of the case studies reviewed here have recent monitoring results presented and analysed in publicly accessible technical reports (**Table 9**). The purpose of technical reports is to present and analyse recent data at regular frequencies (often after every year or 2-3 years of monitoring; **Table 10**). These technical reports have a quick turn-around time, with the time lag between the most recent year of data and the year of publication being 1-2 years. These regular technical reports can aid in the visibility of a monitoring project, however the downside of regular reporting is that the interpretation and discussion of results is often fairly limited. This is the case for example with the technical reports written for Victoria's MNP SRMP (Edmunds *et al* 2010a) and CROP MR fish monitoring programme in New Zealand (Haggitt *et al* 2008). The limited interpretation and discussion of results in the regular technical reports is most often intentional, as results are also presented in scientific papers and/or substantial interpretation and discussion is saved for decadal milestones where long-term results will be reported in more detail (see **Table 9** - monitoring programmes marked with an asterisk). For example the CROP MR New Zealand fish monitoring data is due to be written up into a scientific paper based on 10 years of long-term monitoring data in 2011 (T. Haggit pers comm.), and a book is currently being written based on 20 years worth of coral reef monitoring data from the Kenyan MNPs which is due to be published in late 2011 (T. McClanahan pers comm.).

One disadvantage of only presenting results of monitoring programmes in technical reports is that these are rarely referenced in peer-reviewed scientific papers. Therefore most monitoring programmes also have recently produced scientific papers to share their monitoring results (**Table 10**, see case study scientific papers and additional scientific papers which were assessed in **Appendix 2** (A2.1-A2.6)). The production of scientific papers is considered the primary indicator of scientific productivity, and is the only way to "establish credibility, quality and visibility of a project" (Lindenmayer & Likens 2010). However, the time lag between monitoring and reporting results in scientific papers is substantially longer than for the production of technical reports (which takes 1-2 years; **Table 10**).

For scientific papers, the time lag between data collection and publication ranged from 2-8 years, with the majority of papers being published 3-5 years after the final year of data was collected. In addition to this, the frequency of publication of scientific papers is a lot more sporadic than the 2-3 years for most technical reports. The publication year of the most recent papers which report on monitoring data from each of the case studies and monitoring programmes A2.1 - A2.6 (monitoring programmes from **Appendix 2**) range from 2003-2010. These papers contain data from 1995-2007. These time lags confirm the sentiment that it takes substantially more time to publish scientific papers than technical reports, therefore it is to be expected that the publication of papers is much less frequent. The lack of publication of recent data from the monitoring associated with A2.1 - A2.6 is why these monitoring programmes were not included as case studies in this review.

In many cases the results from monitoring programs have also contributed to global reviews of MPAs (**Table 9**). Contribution to such reviews increases awareness that these long-term monitoring programmes exist and contribute to our further understanding of the effects of MPAs on the marine environment. For example results from the Kenyan MNPs coral monitoring programme have appeared in two large coral reef reviews (International Coral Reef Action Network 2004, Wilkinson 2008), and raw data from the CROP MR in New Zealand and from Anacapa Island within the

Channel Islands MPA network have been used in the first decadal scale assessment of the effect of MPAs (Babcock *et al* 2010).

Results from only three of the monitoring programmes currently feed into non-technical summary reports written by MPA managing agencies. These are for two MPAs: the Great Barrier Reef MP (Great Barrier Reef Outlook Report, Great Barrier Reef Marine Park Authority 2009) and the Channel Islands MPA network (Channel Islands National Marine Sanctuary Condition Report, Office of National Marine Sanctuaries 2009). These non-technical summary reports link the biological measures from individual monitoring programmes to aid in the assessment of conservation objectives at higher ecosystem levels (e.g. ‘biodiversity’ and ‘ecosystem processes’; as was explained in section 6.2.4). These reports are targeted for non-scientific audiences such as managers and members of the public and are an excellent communication tool to demonstrate the state and management of the biological system which is protected by the MPA (i.e. monitoring results, the current status of different indicators and an indication of future management/monitoring planned). Both the Great Barrier Reef Outlook Report (Great Barrier Reef Marine Park Authority 2009) and the Channel Islands National Marine Sanctuary Condition Report (Office of National Marine Sanctuaries 2009) provide reference to the monitoring data and expert judgement used for their high level assessments, however little information is given about how the monitoring data is used to inform the assessment of biological indicators into a simple category to indicate the status of a biological indicator (e.g. Very good, good, poor, very poor for the Great Barrier Reef Outlook Report).

One other non-technical summary report was found for another MPA, which was not included in this review: the Report Card for the Mesoamerica Reef (HRHP 2010) in South America (for further details in **Appendix 2**). This is similar in style to the reports for the Great Barrier Reef MP and the Channel Islands National Marine Sanctuary, however it is missing vital references to the reports/papers which detail the results of marine monitoring data that informed the Report Card (and hence could not be included as a case study in this review).

Table 9. Different reporting styles used by each monitoring programme.

An asterisk (*) denotes monitoring programmes which have the intention of writing detailed assessments of long-term monitoring results in the near future (2011-2012).

Case Study	**Technical Reports**	**Scientific Papers**	**Reviews**	**Non-technical summery reports**
1. Great Barrier Reef MP, Australia - LTMP (coral reef benthic and fish communities)	□	□	□	□
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)	□			□
3. Victoria's MNPs, Australia - SRMP (subtidal reef benthic and fish communities)	□*			
4. Victoria's MNPs, Australia - IRMP (intertidal reef benthic communities)	□*			
5. Tasmania's MRs, Australia - EM (subtidal reef benthic communities)	□*	□	□	
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)	□	□		
7. CROP MR, New Zealand - fish communities	□*	□	□	
8. Channel Islands MPA network, USA - KFM (kelp forest fish communities)		□	□	□
9. Florida Keys NMS, USA - CREMP (coral reef benthic communities)	□	□	□	
10. Florida Keys NMS, USA - CRCP (coral reef fish communities)	□	□		
11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reef benthic and fish communities	*	□	□	

Table 10. Summary of the time lag between reporting of data in technical reports vs scientific (peer reviewed) papers.

This table shows the primary (most recent) reference material used for the 11 case studies and an additional m monitoring programmes (A2.1-A2.6) which were considered for review (but not included as case studies for various reasons, see **Appendix 2**). The dataset duration is specified with the most recent year of data in bold to draw attention to the time lag between the last sampling occasion and the report/paper publication year.

Case Study	Technical Report				Scientific Paper		
	Primary reference - indicating year published	Dataset duration	Time lag	Reporting frequency	Primary reference - indicating year published	Dataset length	Time lag
1. Great Barrier Reef MP, Australia - LTMP (coral reef benthic and fish communities)	Sweatman *et al* (2008)	1993-2007	1 yr	2-3 yrs	Cheal *et al* (2010)	1997-2007	3 yrs
2. Great Barrier Reef MP, Australia - RRMMP (intertidal seagrass)	McKenzie *et al* (2010)	1999-2009	1 yr	1 yr	-		
3. Victoria's MNPs, Australia - SRMP (subtidal reef benthic and fish communities)	Edmunds *et al* (2010a)	1998-2009	1 yr	Every yr of monitoring (2-3 yrs)	-		
4. Victoria's MNPs, Australia - IRMP (intertidal reef benthic communities)	Edmunds *et al* (2010b)	2005- 2009	1 yr	Every yr of monitoring (2-3 yrs)	-		
5. Tasmania's MRs, Australia - EM (subtidal reef benthic communities)	Barrett *et al* (2006)	2000-2006	<1 yr	Infrequent	Barrett *et al* (2009)	1993-2002	7 yrs
6. Jervis Bay MP, NSW, Australia - EM (subtidal reef benthic and fish communities)	Barrett *et al* (2007)	1996-2007	<1 yr	Infrequent	-		
7. CROP MR, New Zealand - fish communities	Haggitt *et al* (2008)	2000-2008	<1 yr	Every yr of monitoring (2-3 yrs)	Shears & Babcock (2003)	1978-2000	3 yrs
8. Channel Islands MPA network, USA - KFM (kelp forest fish communities)	-				Hamilton *et al* (2010)	1999-2007	3 yrs
9. Florida Keys NMS, USA - CREMP (coral reef benthic communities)	Ruzicka *et al* (2010)	1996-2008	2 yrs	2 yrs	Maliao *et al* (2008)	1996-2000	8 yrs
10. Florida Keys NMS, USA - CRCP (coral reef fish communities)	Bohnsack *et al* (2009)	1994-2007	2 yrs	unknown	Ault *et al* (2006)	1999-2004	2 yrs
11. Malindi, Watamu and Mombasa MNPs, Kenya, Africa - coral reef benthic and fish communities	-				Muthiga (2009)	1993-2005	4 yrs

Case Study	Technical Report				Scientific Paper		
	Primary reference - indicating year published	Dataset duration	Time lag	Reporting frequency	Primary reference - indicating year published	Dataset length	Time lag
A2.1 Kingston Reef Sanctuary, Rottnest Island, Western Australia - density and size of reef fish	-				Kleczkowski *et al* (2008)	2002-2003	5 yrs
A2.4 Sumilon and Apo Island Marine Reserves, Philippines - biomass of targeted fish	-				Alcala *et al* (2005)	1983-2001	4 yrs
A2.5 Cote Bleue Marine Park, France - size and abundance of reef fish	-				Claudet *et al* (2006)	1995-2001	5 yrs
A2.7 Canary Islands Network for Protected Natural Areas, Spanish Territory, Africa - biomass and abundance of commercially-targeted fish species	-				Tuya *et al* (2006)	2004	2 yrs
A2.8 Northern KwaZulu-Natal Marine Reserves, South Africa - coral reef monitoring	-				Schleyer & Tomalin (2000)	1994-1995	5 yrs
A2.11 Las Cruces Marine Protected Area, Chile - rocky intertidal species targeted for harvesting	-				Navarrete *et al* (2010)	1981-2006	4 yrs

7 Discussion

This review has introduced eleven case studies which are considered best-practice examples of long-term MPA monitoring programmes from around the world. These are long-term (greater than five years) biological monitoring programmes which focus on evaluating 'no-take' areas within MPAs. These monitoring programmes occur within MPAs which are actively managed, and monitoring is done by scientists or managing agencies. The primary resources utilised in this review include recent (from 2006 onwards) publicly available scientific papers and government reports. This review therefore reflects the level of external reporting, and most likely the public awareness of each monitoring programme.

This Discussion evaluates the case studies against the four key components of a good monitoring framework. This evaluation is discussed in the wider context of environmental monitoring and experimental marine ecology where considerable attention has been paid to monitoring/experimental design, data analysis and reporting of results. The issues discussed in relation to these MPA case studies are applicable to all types of environmental monitoring. The issues and lessons learned from this discussion should help improve the scientific credibility and success of current and upcoming marine monitoring programmes.

7.1 Key questions posed

There is a hierarchy of questions which should be specified for all monitoring programmes in order to ensure that the system of interest will be monitored and assessed in the most ecologically relevant way. This hierarchy of questions contribute to the high level MPA conservation objectives, the intermediate level of monitoring programme objectives and the detailed level of monitoring programme hypotheses. All monitoring programmes reviewed here do not adequately consider this hierarchy of questions, primarily through failing to link MPA conservation objectives and monitoring programme objectives, and through failing to explicitly state monitoring programme hypotheses.

Biodiversity protection and resource management (e.g. fisheries management) are the two primary ecological objectives of establishing MPAs (Sobel & Dahlgren 2004, Partnership for Interdisciplinary Studies of Coastal Oceans 2007, UNEP-WCMC 2008). All MPAs investigated in this review have conservation objectives which relate to biodiversity, through aims such as to "protect/maintain/preserve biodiversity" and to "maintain ecosystem/natural processes" (e.g. California Department of Fish and Game 2004, Victorian Government 2004, NSW NSW Government 2007, National Oceanic and Atmospheric Administration 2007, Australian Government 2010). The lack of more specific conservation objectives has been highlighted as an issue for Mediterranean MPAs, where Garcia-Charton *et al* (2008) suggest that conservation objectives of MPAs should be defined so that the 'attainment of those conservation objectives can be met' through monitoring and research. In the hierarchy of good questions, this means that conservation objectives of an MPA should be defined in such as way that more detailed and specific monitoring programme objectives and hypotheses can be easily derived from MPA conservation objectives. This has not been done by any of the MPAs reviewed here.

None of the monitoring programmes reviewed here acknowledge the conservation objectives of the MPA which they are monitoring. Instead authors of reports/papers which present the results of the monitoring programmes focus on specifying the objectives of their monitoring programme only. The failure to link monitoring programme objectives with conservation objectives is a concerning observation; however it seems that this is a common occurrence in conservation biology. This has been highlighted in the past by Fazey *et al* (2005) who pointed out the alarming statistic that only 13% of conservation biology scientific papers from 2001 which were reviewed in their study had high relevance to policy and management through acknowledging and testing/reviewing conservation objectives. It seems that MPA monitoring programmes suffer a similar low rate of acknowledgement of conservation objectives. This may be in part due to the lack of funding/integration of monitoring programmes between scientists and MPA managing agencies.

It is only in non-technical summary reports where MPA conservation objectives, relating to biodiversity and ecosystem/natural processes, are translated into smaller components at the habitat or species level (relevant to monitoring programmes). This can be seen in the Great Barrier Reef Outlook Report (Great Barrier Reef Marine Park Authority 2009); the Channel Islands NMS Condition Report (Office of National Marine Sanctuaries 2009); and the Report Card for the Mesoamerica Reef (HRHP 2010). In these reports, biological measures (such as groups of species, e.g. corals) from individual monitoring programmes are attributed to different types of ecosystem level measurements (such as habitats) which contribute to an understanding of 'biodiversity' and 'ecosystem processes' (as was explained in section 6.2.4). These ecosystem level measurements are not however directly linked with monitoring programme objectives.

All case studies have clearly defined monitoring programme objectives. Most aim to assess differences between MPA ('no-take') and reference sites, while other case studies also aim to assess long-term temporal trends and spatial differences within MPAs. These monitoring programme objectives are however rarely translated into specific hypotheses which relate to the habitats and species which are being monitored. In fact only two monitoring programmes translate their general monitoring objectives into specific hypotheses to test their monitoring data. These are the fish monitoring programmes from the Channel Islands National Marine Sanctuary (Case Study 8; Hamilton *et al* 2010) and the Florida Keys NMS (Case Study 10, Bohnsack *et al* 2009). Both of these monitoring programmes specify the direction of the predicted effect, by hypothesising that targeted/exploited fish species will increase in no-take areas compared to reference areas. They also hypothesise that there will be no effect of reserve protection on non-targeted fish species. These case studies however do not quantify the magnitude of the predicted effects (effect size). No other case studies make any reference to a hypothesis or predicted effect size. The implication of the failure to define an effect size is discussed further in section 7.3.1.

The formulation of a clear hypothesis (including the effect size and direction of the effect) is a crucial initial step before monitoring begins. This ensures the appropriate choice of biological indicator, monitoring programme design and statistical analysis required to demonstrate a predicted effect within the system of interest (Wolfe *et al* 1983, Underwood 1990, Fairweather 1991, Mapstone 1995, Guidetti 2002, Quinn & Keough 2002, Lindenmayer & Likens 2010). This review has shown that many current long-term MPA monitoring programmes fail to explicitly state any hypotheses about the monitored system. Given that the lack of clear hypotheses is a common reason why long-term monitoring programmes fail to detect effects and ultimately fall down (Wolfe *et al* 1983, Lindenmayer & Likens 2010); this is a very concerning observation of the current state of marine biological monitoring associated with MPAs.

There are only some occasions where forming clear hypotheses may not be of use in MPA monitoring programmes. This is for indirect effects of MPAs, such as the biodiversity of plants and invertebrates, where scientific knowledge is limited and MPA effects cannot be predicted. In these cases Edgar & Barrett (1999) have suggested that it may be best to merely observe the serendipitous effects of MPAs on these species. It is these unexpected observations that will reveal information about an ecosystem. These observations can then lead to the formulation of new hypotheses. Such an approach is also advocated in order to detect unexpected natural or anthropogenic impacts (Castilla 1988, Anderson & Thompson 2004, Wintle *et al* 2010). Scientists should approach such 'curiosity-driven or passive' monitoring (as coined by Lindenmayer & Likens 2010) with caution however, as their utility to the application of adaptive management is likely to be limited without any clear monitoring objectives or hypotheses. The lack of monitoring objectives is also likely to be an issue when seeking funding for monitoring, as strong justifications for monitoring are now required in our current global economic climate where funding for environmental monitoring can be scarce.

7.1.1 Biological indicators

The final step in posing a hierarchy of key questions is the choice of biological indicator used to address hypotheses, monitoring objectives and conservation objectives. Only three monitoring programmes reviewed here justify the relevance of their biological indicator(s) at an ecosystem level which generally relates to the monitoring programme objectives. These justifications include: seagrass beds are an indicator of ecosystem health (McKenzie *et al* 2010); shallow rocky reefs are an important component of the marine environment due to their high biological complexity, species diversity and productivity (Edmunds *et al* 2010a); and, fish species from rocky reefs are heavily exploited and are therefore likely to show the greatest change following protection (Barrett *et al* 2007). It is also in the cases where non-technical summary reports are produced, that biological indicators are linked to different types of ecosystem level measurements which contribute to an understanding of 'biodiversity' and 'ecosystem processes'. The most thorough explanation of the use of biological indicators is for the Mesoamerica Reef (McField & Richards Kramer 2007)[8]. In the Mesoamerica Reef 'Guide to Indicators' report (McField & Richards Kramer 2007), 24 biological indicators (e.g. coral diversity, fish abundance, mangrove aerial extent and coral to algae ratio) are described in relation to two (Ecosystem Structure and Ecosystem Function) of the four main components which are used in the Report Card to assess the 'health' of the Mesoamerican Reef (McField & Richards Kramer 2007).

In general, near shore rocky reefs or coral reefs are the most commonly monitored habitats within no-take MPAs based on the case studies considered in this review, and in the wider body of MPA monitoring literature (e.g. Babcock *et al* 1999, Alcala *et al* 2005, Guidetti & Sala 2007, Partnership for Interdisciplinary Studies of Coastal Oceans 2007, Lester & Halpern 2008, Barrett *et al* 2009, Lester *et al* 2009, Stewart *et al* 2009, Babcock *et al* 2010, Hamilton *et al* 2010, Russ & Alcala 2010). Most often MPA monitoring programmes use multiple species of fish, invertebrates and algae as biological indicators, with targeted/exploited fish and invertebrates being the focus of some monitoring programmes to assess direct effects of reserve protection, whilst benthic invertebrates and algae are the focus of other monitoring programmes to assess indirect effects of reserve protection.

The focus of monitoring on exploited/targeted fish and invertebrates from coral and rocky reefs seems to be of particular interest to scientists, and is likely to be because they are indicators that perform well and demonstrate direct (and often fairly quick) effects of reserve protection due to restriction of fishing activities (as has been shown in MPA literature, e.g. Babcock *et al* 1999, Alcala *et al* 2005, Ault *et al* 2006, Claudet *et al* 2006, Partnership for Interdisciplinary Studies of Coastal Oceans 2007, Lester & Halpern 2008, Lester *et al* 2009, Babcock *et al* 2010). This is formally acknowledged in one of the case studies as a justification for the choice of targeted fish as biological indicators (Barrett *et al* 2007), however no other monitoring programmes have made such formal justifications. The protection of targeted/exploited species is inherent in the creation of no-take MPA's, however resource protection is not a specified conservation objective of any of the MPAs reviewed here (instead conservation objectives relate to biodiversity). Therefore the relevance of biological indicators to conservation objectives relating to biodiversity is unjustified in most of the monitoring programmes.

The final consideration in the choice of biological indicators is the direction of the predicted effect of MPA protection. MPAs will have direct positive effects on some species (such as targeted fish and invertebrates), indirect negative effects on some species (e.g. decline in sea urchins as a result of increased fish predation), and indirect positive effects on other species (e.g. increase in macroalgae cover due to reduced urchin grazing) (as demonstrated by Babcock *et al* 1999). Thus, the biological indicators monitored must be considered carefully in reference to ecosystem processes, and the

[8] Interestingly the Report Card for the Mesoamerica Reef (HRHP 2010) suggests that many monitoring programmes contribute to reporting on the health of the Mesoamerica Reef, however no reports/papers which detail marine monitoring results that informed the Report Card can be found. See Appendix 2 for further information collated on this potential case study.

interactions that exist between species. As was stated previously, the direction of the predicted effect should be specified in the hypothesis.

The failure of the majority of case studies to justify the relevance of their biological indicator(s) has serious implications for MPA monitoring programmes and MPA management. By failing to explicitly state what a biological indicator is indicative of in terms of the wider marine environment and MPA conservation objectives, then the results of a monitoring programme are at risk of being mis-interpreted by scientists and managers. This could be to the detriment of the MPA or the scientific community's knowledge about MPAs. This is just another issue highlighted by Lindenmayer & Likens (2010) which can lead to the downfall of monitoring programmes.

7.2 Monitoring programme design

Good monitoring design is crucial to the success of a monitoring programme in detecting the biological effects of scientific interest. In the context of MPAs, good monitoring design is vital to prevent incorrect conclusions being made about the effects of MPAs and possibly leading to inappropriate management measures (Fairweather 1991, Osenberg *et al* 2006, Claudet & Guidetti 2010).

Monitoring/sampling/experimental design has been the subject of substantial development and discussion in Environmental Impact Assessment (EIA) and experimental marine ecology (e.g. Green 1979, Skalski 1990, Underwood 1991, Schmitt & Osenberg 1996, Keough & Mapstone 1997, Underwood *et al* 2000, Benedetti-Cecchi 2001, Hewitt *et al* 2001, Stewart-Oaten & Bence 2001, Downes *et al* 2002). In these fields, monitoring programmes or experiments are designed to detect differences in a response variable (e.g. individual species abundance/biomass or community measures) between experimental treatments of interest, or between impacted (e.g. near a sewage outfall) and reference areas. The most common design for monitoring environmental impacts is BACI (Before, After, Control, Impact) which was introduced by Green (1979). This design allows for the comparison of data from Before and After a disturbance/impact occurs, at both the potentially Impacted and Control sites (Downes *et al* 2002). There have been many modifications of the basic BACI design, which incorporate increased replication over time (e.g. paired BACI (BACIP); Stewart-Oaten *et al* 1986, Osenberg *et al* 1994), increased replication of Control locations (e.g. multiple BACI (MBACI); Keough & Mapstone 1997), and increased replication at different spatial scales within Control and Impact locations and asymmetrical design to incorporate multiple Control locations (Beyond BACI; Underwood 1991). The BACI principles of monitoring design have formed the basis for most impact and conservation related monitoring programmes on a global scale.

Despite the vast amount of literature which exists on EIA monitoring design, only a few MPA scientists have advocated its direct relevance to MPA monitoring approaches (Fraschetti *et al* 2002, Guidetti 2002, Lincoln-Smith *et al* 2006, Osenberg *et al* 2006, Claudet & Guidetti 2010). The BACI design can be directly applied to the monitoring design required to evaluate the effectiveness of MPAs, but rather than having an Impact location there is the 'MPA' or 'no-take' location, and the Control location is often referred to as a 'Reference' or 'Fished' site. Before and After no longer relate to an impact or disturbance, but the time when the MPA was established[9]. The establishment of an MPA can therefore be considered as a good 'disturbance'. All of the case studies reviewed here followed the BACI principles of monitoring design, although most fail to acknowledge this.

The case studies which aim to assess the effect of the MPA, monitor sites within their MPAs (no-take) and Reference areas. Only three monitoring programmes do not monitor Reference locations (Great Barrier Reef MP seagrass and coral reef (LTMP) monitoring and the Florida Keys NMS coral reef monitoring programmes), as these are designed to primarily monitor temporal and spatial trends within their large MPA networks. Most of the monitoring programmes began before the

[9] MPA establishment is assumed to be when active management begins. If this is not the case, then Before/After refers to the time when active management begins.

implementation of the MPAs, giving crucial Before data to compare the effectiveness of the MPAs to After establishment data. However, five of the monitoring programmes began between up to two years After MPA establishment. The lack of Before data is a common issue in EIA monitoring (particularly when there is no warning of an impact; Castilla 1988, Glasby 1997, Terlizzi *et al* 2005) and it is equally as common in MPA monitoring (more so because of a lack of foresight of MPA managing agencies; Fraschetti *et al* 2002, Guidetti 2002, Willis *et al* 2003, Stewart *et al* 2009, Claudet & Guidetti 2010). The lack of Before data makes it more difficult to demonstrate causality of the effect MPA protection. It is however possible to use a deconstructed BACI design such as After, Control, Impact (ACI) designs (as has been done in impact assessment, e.g. Galsby 1997) and make spatial comparisons of temporal trends after MPA establishment (Osenberg *et al* 2006).

The importance of spatial and temporal replication of data collected in monitoring programmes has also been an area of great discussion in EIA monitoring (Green 1979, Underwood 1991, 1993, Osenberg *et al* 1994, Underwood *et al* 2000, Downes *et al* 2002, Quinn & Keough 2002). Inadequate replication to capture spatial and temporal variation will lead to inconclusive monitoring results and the inability to make inferences about the system of interest (Underwood 1990). The incorporation of replication to address natural spatial and temporal variation in monitoring design has also been highlighted as vital in evaluating the effects of MPAs (Garcia-Charton & Perez-Ruzafa 1999, Guidetti 2002, Lincoln-Smith *et al* 2006, Osenberg *et al* 2006). Many case studies stratify their sampling effort to address potential for natural variation between Regions/Sectors/Bioregions and different habitats. All case studies reviewed here have good spatial coverage, and incorporate different levels of spatial replication through having multiple MPA/Reference locations, Sites within Locations and most often replicated sampling units within Sites. Only three monitoring programs have insufficient replication of sampling units within Sites (Case Studies 3, 5 and 6; which only have one 200m transect within each site, which are inappropriately treated as four independent 50m transects). All of these programmes have stemmed from the one method developed by Edgar & Barrett (1997), and the main implication that this has for these monitoring programmes is that Sites must be treated as replicates, rather than the four 50m non-independent transects within each Site.

The temporal replication of all monitoring programmes occurs mostly at two levels (Before/After, and multiple years within Before/After). Some monitoring programmes have continued to monitor on an annual basis, whilst other have reduced their monitoring frequency to once every three years. The case studies which have had the temporal frequency of their monitoring programmes reduced are those which are contracted to marine consultants (Victoria's MNPs subtidal and intertidal reef monitoring and CROP MR New Zealand fish monitoring) and in one case which monitoring is done by an independent scientists (Jervis Bay MNP subtidal reef monitoring). The reasoning for the reduction in temporal frequency does not appear to be biologically justified; instead it seems to be due to MPA management instructions (in the case of Victoria's MNPs and CROP MR New Zealand), or a lack of continuity in funding and change in scientists who lead the monitoring (in the case of Jervis Bay MNP, where monitoring has been transferred from independent scientists to the managing agency).

The choice of random or fixed factors in space (e.g. Location, Site and sampling unit) is a contentious one, and ultimately depends on whether scientists are interested in a specific location (fixed factor) or a location which is treated as a representative of all possible locations in order to make generalisations about all locations (random factor; Stewart-Oaten *et al* 1986, Downes *et al* 2002, Quinn & Keough 2002). Only four monitoring programmes state that their sampling units are randomly/haphazardly positioned within Sites, and therefore can make generalisations about areas beyond where they have monitored. The majority of monitoring programmes reviewed here on the other hand have fixed transect/quadrats and Locations/Sites which have been repeatedly surveyed through time. This means that conclusions drawn from these monitoring programmes can only be about the transects/quadrats and Locations/Sites that are monitored, and greater generalisations in a larger spatial context cannot be made. Having fixed sampling units allows for a more powerful statistical test to be conducted, as the potential for spatial variation in a monitoring dataset is reduced (compared to having random sampling units), therefore patterns associated with change through time may be detected more easily. This type of monitoring design does lead to the non-independence of sampling units through time, and therefore requires special statistical analyses to deal with this non-independence (e.g. Repeated Measures ANOVA, Green, 1993).

There are no major flaws in monitoring designs used in any of the monitoring programmes reviewed here. This is supportive of the observation made by Claudet & Guidetti (2010) who found that all MPA fish studies in the Mediterranean which recently published results (from 2002-2010) follow the BACI principles of monitoring design and have appropriate levels of spatial replication. This is an improvement on MPA monitoring programmes from the past which have been criticised for having flaws in their monitoring design (Stewart *et al* 2009, Claudet & Guidetti 2010).

Finally the data collection methods used in most monitoring programmes includes the use of SCUBA divers to make visual counts of taxa, with only two monitoring programmes currently using video footage or stills (collected by divers) to estimate biological units. It is surprising that so few monitoring programmes use these more remote methods. It may be that because many of these monitoring programmes began in the 1990s and early 2000s, they have continued with their original methodology rather than taking on more modern techniques such as using video/stills, which are generally regarded to maintain accuracy and repeatability of data collected through time (Mitchell & Coggan 2007).

7.3 Data analysis and presentation

The purpose of this review is not to conduct a meta-analysis of the types and magnitude of biological effects that result from MPA protection that have been reported in the case studies. Instead this section of the Discussion will cover the types of graphical presentation and statistical analysis techniques used to evaluate the effects of MPAs.

A variety of graphical presentation and statistical analysis techniques are used to demonstrate the effects MPAs in the case studies reviewed here, in fact very few case studies share common techniques. These techniques are used to demonstrate the effects of MPAs over time and space. Given that all case studies reviewed are ‘long-term’ MPA monitoring programmes, there is an emphasis on demonstrating the effects of MPAs over time. Statistical analysis techniques (with supporting graphical presentation techniques) are therefore generally used to do one of two things: 1) to define the form of temporal trends associated with MPAs, or 2) to evaluate the differences in temporal trends between MPA and Reference sites through time.

All of the case studies follow the BACI principles of monitoring design (with various levels of deconstruction, e.g. some case studies are missing ‘Before’ monitoring data and some others do not monitor ‘Control’ sites). It is no surprise therefore that the majority of statistical analysis techniques used in the MPA monitoring case studies (outlined in section 5.4.1 and **Table 8**) are the same as the statistical techniques commonly used in marine EIA (as outlined in **Appendix 3**). In EIA, some of the most common univariate[10] statistical techniques include Analysis of Variance (ANOVA)[11] and Repeated Measures ANOVA[12]. The most common multivariate[13] statistical techniques include non-metric Multi Dimensional Scaling (nMDS) plots[14], Similarity Percentage (SIMPER) analysis[15] and Analysis of Similarity (ANOSIM)[16].

[10] Univariate data is a single response variable (e.g. species level data (abundance or cover) or a single measure of species diversity).
[11] ANOVA is used to test for differences between factors such as Time (Before and After) and Site (Control and Impact) (Underwood 1991, 1997b, Benedetti-Cecchi 2001).
[12] Repeated Measures ANOVA is similar to ANOVA, however Time (which is a factor in the analysis) is treated as non-independent, therefore the test must be accordingly adjusted (Green 1993).
[13] Multivariate data is a matrix of multiple response variables (e.g. community or assemblage data composed of multiple species).
[14] nMDS plots are a multivariate ordination technique used to visualise multivariate data in generally 2-3 dimensions (often used to investigate factors such as Space and Time) (Clarke and Warwick 2001).

The univariate statistical analysis techniques used in the MPA monitoring case studies which are the same as the techniques used in EIA are: ANOVA (used to test temporal trends; e.g. Great Barrier Reef MP seagrass monitoring, McKenzie *et al* 2010), and Repeated Measures ANOVA (used to test temporal trends and to test for differences between MPA and Reference sites over time; e.g. Florida Keys NMS coral monitoring, Ruzicka *et al* 2010). The use of ANOVA can be inappropriate if steps aren't taken to deal with the likely non-independence (or auto-correlation) of Time (which is a factor in the analysis of temporal trends). This is where Repeated Measures ANOVA is much more appropriate, as the test is adjusted to deal with the non-independence of Time (Green 1993). There was only one case of mis-use of a statistical technique encountered in this review, and this was the use of analysis of covariance (ANCOVA)[17] in the Channel Islands National Marine Sanctuary fish monitoring (Hamilton *et al* 2010). Time was used as a co-variate, however a more appropriate test would have been Repeated Measures ANOVA where Time is a regular factor in the analysis.

A novel use of a univariate statistical technique seen in this review is 95% Confidence Intervals (CIs) used by Bohnsack *et al* (2009). Here CIs were used to evaluate fish abundance data from before to after no-take establishment of the Florida Keys NMS (see section 5.4.1; **Figure 2a**; Case Study 10 in **Appendix 2**). This very simple statistical technique is used to interpret a complex amount of data (Before (baseline) and After data; No-take and Reference sites; Exploited and Non-exploited fish species). Bohnsack *et al* (2009) hypothesize that exploited fish species will increase in MPA (no-take areas) compared to reference areas, and that there will be no effect of MPA on non-targeted fish species. The use of 95% CI as an alternative to statistical significance tests and is considered more intuitive by some (e.g. Fidler *et al* 2006), and in this case certainly allowed Bohnsack *et al* (2009) to make a strong conclusive statement confirming all hypotheses were validated by the data and analyses.

The majority of monitoring programmes only used univariate statistical techniques to evaluate their MPA monitoring data. The only multivariate statistical technique used to test for differences between MPA and Reference sites over time was SIMPER analysis which was used by Barrett *et al* (2009) to determine influential species which contribute to differences between no-take and reference areas over time. This test is supported by the graphical representation of data in an nMDS plot (**Figure 6**). nMDS plots are also used in four other case studies to graphically present assemblage level data. The use of nMDS plots with many data points and no supporting formal multivariate statistical test can be of limited utility and potentially confusing to readers (as was demonstrated in **Figure 8**; Case Study 3). It is surprising that no other multivariate statistical tests are used to test assemblage level differences between sites over time in the MPA monitoring programmes reviewed here. It appears as though MPA scientists primarily use multivariate statistics to assess spatial rather than temporal differences. The multivariate techniques commonly used EIA such as SIMPER and ANOSIM, along with many other multivariate techniques outlined by Clarke & Warwick (2001) could be used for the type of assemblage level data that is collected by most of these monitoring programmes. The only issue with multivariate statistical techniques is that it is more difficult to establish a hypothesised effect of an MPA on an assemblage compared to individual species, therefore a significant multivariate test may be more difficult to interpret in terms of evaluating the effectiveness of an MPA.

The statistical tests commonly used in EIA can be limited in their utility for evaluating long-term MPA data, as they predominantly focus on testing differences between groups of data (e.g. Before vs After impact), rather than temporal trends. The effect of MPAs can be more subtle and take a much longer time to establish (e.g. up to 13 years for indirect MPA effects, Babcock *et al* 2010) compared

[15] SIMPER is a test used to determine influential species which contribute to differences between factors (e.g. Time and Space) (Clarke and Warwick 2001).
[16] ANOSIM is essentially ANOVA for multivariate assemblages, which tests for differences between 1-2 factors (Clarke and Warwick 2001).
[17] ACOVA is used in a similar way to ANOVA, with the addition of a continuous variable of interest (e.g. a physical parameter of water quality) which is included to help attribute some of the unaccounted for variation in the analysis (Quinn and Keough 2002).

to some environmental impacts which can be detected almost immediately following an impact (e.g. Castilla 1988, Schroeter *et al* 1993, Keough & Quinn 1998, Roberts *et al* 1998). This is likely to be why some of the MPA monitoring case studies here do not use formal statistical tests to assess their MPA data and instead only present their data graphically and describe the temporal trends (e.g. positive, negative, no trend). Statistical analysis approaches to assessing long-term temporal trends in MPA data have rarely been discussed in the literature, compared to the vast discussions dedicate to statistical techniques used for EIA (e.g. ANOVA; Underwood 1991, 1997, Benedetti-Cecchi 2001). This is most likely to be because as yet there are few cases of truly 'long-term' MPA monitoring datasets (according to Babcock *et al* (2010) only six MPA monitoring programmes have reported over one decade's worth of data in the scientific literature).

Barrett *et al* (2007) have suggested that non-linear regression or generalised linear models may be appropriate alternatives to the traditional statistical tests used to analyse long-term MPA monitoring data. Similar techniques have been used in three of the case studies here: Linear mixed effect models (LMEM) used to determine temporal trends of coral and fish within the Great Barrier Reef MP (Sweatman *et al* 2008); Generalised mixed model regression (GMMR) used to determine temporal trends of coral within the Florida Keys NMS (Ruzicka *et al* 2010); and, Spearman Rank Correlation Coefficients (SRCC) used to determine serial convergence or divergence in the abundance of subtidal reef species between Reserve and Fished areas over time in Tasmania's MRs (Barrett *et al* 2009). Each of these approaches are variations on the same theme of determining long term trends (however the tests have different assumptions and steps of analysis). However, LMEM and GMMR focus on determining the form and direction of temporal trends, while SRCC is slightly different as this is a significance test (which can be related to a hypothesis) used to determine the difference between MPA and Reference sites over time. These different approaches require different styles of interpretation to adequately inform management.

Other approaches used to analyse long-term data in the scientific literature include Generalised Linear Mixed Models (e.g. New Zealand MPAs, Shears & Babcock 2003), Repeated Measures ANOVA (e.g. Philippines MPAs, Russ & Alcala 2003, Alcala *et al* 2005), ANOVA (e.g. Tasmania's MPAs, Edgar & Barrett 1999), non-parametric multivariate ANOVA (e.g. New Zealand MPAs, Shears & Babcock 2003), and non-linear regression (e.g. Kenya's MPAs, McClanahan *et al* 2007; and Philippines MPAs, Russ & Alcala 2010). As can be seen, there are a variety of techniques used in the case studies reviewed here and more generally in the scientific literature, with very little overlap in approaches to statistical analysis.

There is clear information gap in the scientific literature in regards to discussion about approaches to statistical analysis of long-term MPA monitoring data. As more MPA monitoring programmes will be reaching 'long-term' status in the coming years, now is the time for marine scientists and statisticians to discuss approaches to statistical analysis of long-term MPA monitoring data in the scientific literature. This should make full use of lessons learned from EIA, experimental marine ecology and other areas of science. In particular, discussions should focus on the need to have statistical tests which are supported by hypotheses and enable clear interpretation of results. One approach which may be suitable in terms of determining long-term trends whilst fitting a hypothesis and effect size to a long-term dataset is the use of process control charts. Control charts were developed originally for manufacturing applications (Montgomery 2009), and have been introduced by Anderson & Thompson (2004) as a useful statistical technique to track marine biological systems under long-term observation. The statistical details of control charts will not be discussed here, but they certainly should be considered to address the need for the use of statistical hypothesis testing to determine long-term MPA marine monitoring datasets.

There are two novel graphical presentation examples (independent of statistical analysis) which demonstrate the effect of MPAs which were encountered in this review: a plot of the Average Response Ratio (ARRs) of targeted and non-targeted fish in the Channel Islands reserves to demonstrate the effect of MPAs vs reference sites (see section 6.4.3; **Figure 9**; Hamilton *et al* 2010); and a plot of the change in presence/absence of coral species in the Florida Keys NMS (see section

6.4.3; **Figure 10**; Ruzicka *et al* 2010). As was mentioned previously very few case studies share common graphical presentation or statistical analysis techniques, so at a minimum this review should increase awareness about the different and novel techniques used in MPA monitoring programmes around the world.

7.3.1 Issues with statistical inference

An introduction to the issues with statistical inference (decision making using frequentist statistical tests) is provided in **Appendix 4**. These issues are namely Type I and II errors, which can lead to incorrect conclusions about patterns in the marine environment (Green 1979, Fairweather 1991, Mapstone 1995, Underwood 1997, Quinn & Keough 2002). A substantial amount of literature discusses the pitfalls of statistical inference in marine ecology. This literature highlights the steps that scientists should take to address these issues. However in practice, very few scientists (even in experimental marine ecology and EIA) demonstrate that they have fully considered these issues (Peterman 1990, Fairweather 1991, Fidler *et al* 2006).

As was mentioned in **Appendix 4**, a Type I error is the significance level (α or p-value) of a statistical test and is conventionally set at 0.05 (Underwood 1997, Quinn & Keough 2002, Underwood & Chapman 2003). Statisticians must be aware of this when conducting repeated significance tests on the same dataset, as there is a danger of making a Type I error (detecting a significant effect, when in fact it is not significant; Underwood 1997, Quinn & Keough 2002, Underwood & Chapman 2003). Of the seven MPA monitoring case studies which used significance tests to evaluate the effects of their MPA, only one made reference to the potential for Type I error. This was the Florida Keys NMS coral monitoring programme (Case Study 9, Ruzicka *et al* 2010) which used Bonferroni correction and adjusted p-values to address the potential for Type I errors due to repeating the same ANOVA test on multiple region and habitat groupings of the one coral monitoring dataset.

The issues associated with Type II error are more complex and thus a greater concern in statistical inference. A Type II error is no significant difference detected, when in fact one has occurred. Type II error is inversely related to statistical power which includes the variation inherent in the system being monitored, the effect size to be detected (the magnitude of difference between groups), the sample size, and the significance level of the test (Green 1989, Fairweather 1991, Osenberg *et al* 1994, Mapstone 1995). Unless controlled by the researcher, Type II error rates can be very high (Fairweather 1991).

There are many issues associated with failing to consider Type II error, power and effect size. These occur at different stages of the monitoring programme: 1) prior to beginning a monitoring programme, and 2) at the data analysis stage of a monitoring programme.

a Prior to beginning a monitoring programme: Failure to consider Type II error, power and effect size

By failing to consider Type II error, power and the predicted effect size prior to beginning monitoring (i.e. at the planning stage), the required number of replicates to detect an effect of interest will be unknown. Of all of the MPA monitoring case studies, only one demonstrated that effect size was considered prior to beginning a monitoring programme. This was for the Channel Islands MPA network fish monitoring programme. In the Channel Islands MPA network Monitoring Plan (California Department of Fish and Game 2004), the expected effect size for the abundance and size of different species of fish and invertebrates between MPA and Reference sites was specified. These effect sizes were calculated based on existing data collected by the National Park Service and PISCO, who are the primary scientists who conduct the kelp forest monitoring (for further details see Case Study 8, **Appendix 1**). Surprisingly, the calculated effect sizes are however not used to help inform the sample size required to conduct monitoring in order to detect an effect of interest, and are not referred to in the most recent discussion of monitoring results (Hamilton *et al* 2010).

This review has only revealed one good example where power and effect size have been considered to determine sample size prior to beginning a monitoring programme. This is for a new monitoring programme of the Dampier Archipelago Marine Park in Western Australia (Armstrong 2009; see **Appendix 2**, A2.1). Armstrong (2009) uses power curves to demonstrate how varying the power and effect size of coral cover affects the number of replicate transects needed for the monitoring programme. No results have been published from this monitoring programme to date (hence it was not included as a case study), therefore it is not possible to evaluate whether this work prior to the monitoring programme has resulted in a higher detection real effects of interest (significant effects) and non-significant effects (with high power). It may be that other monitoring programmes reviewed here have considered power and effect size prior to beginning monitoring, however the failure to mention this in publications has led to questions about the scientific integrity of these monitoring programmes.

The general failure of MPA monitoring programmes to consider predicted effect sizes should be no longer excusable in the scientific community. As was mentioned in section 7.1, all scientists should consider the predicted effect of MPA establishment on marine species which they are monitoring. This should be translated into a formal hypothesis which outlines the direction of the predicted effect (e.g. species abundance will increase/decrease within an MPA) and the predicted effect size for different species (e.g. 50% higher abundance within an MPA). There is enough existing MPA literature (and reviews of MPA literature) that demonstrates many effect sizes of species directly and indirectly effected by MPAs around the world (e.g. Claudet *et al* 2008, Lester & Halpern 2008, Lester *et al* 2009, Stewart *et al* 2009, Babcock *et al* 2010). These effects are by no means simple or standard for different species in different habitats and areas around the world; however they can give an indication of the types of effect that scientists beginning monitoring should be designing their monitoring programme to detect. Willis *et al* (2003) have discussed the difficulties in choosing an effect size for the species of interest, and have highlighted that a 100% increase in density of any species should considered as a minimum effect size in the naturally variable marine environment to demonstrate the effect of an MPA.

To date effect sizes have generally been considered spatially (i.e. the difference between MPA and Reference sites); however there should also be a temporal component to setting an effect size. Based on key MPA monitoring programmes which span over a decade, Babcock *et al* (2010) outlined the time expected to detect MPA effects is on average 5.13 ± 1.9 years to detect direct effects on target species, and much longer (13.1 ± 2.0 years) to detect indirect effects on other species. This recent information should be taken into account for all MPA monitoring programmes, as such length of time to detect direct and indirect effects of MPAs is a strong argument for the necessity of long-term monitoring programmes, and will help justify the potential lack of significant effects detected within the initial years of a monitoring programme.

b Data analysis stage of a monitoring programme: Failure to consider power of non-significant effects

By failing to consider power at the data analysis stage of a monitoring programme, there is no way to establish whether a non-significant effect is truly non-significant (with high power) or not. A reason why a non-significant effect may not be a true effect is because the statistical test had low power due to poor sampling design, which did not take into account natural variation and the predicted effect size for a species. The only way to establish whether a non-significant effect is truly non-significant (with high power) is through calculating 'post-hoc' power (Toft & Shea 1983, Andrew & Mapstone 1987, Peterman 1990, Fairweather 1991, Thomas 1997).

No case studies conduct post-hoc power calculations for non-significant effects presented in their reports/papers. This is a concerning observation, as MPA literature seems to be dominated by the discussion of significant effects, but not non-significant effects with high power. Some case studies mentioned sampling issues with spatial variability which may have contributed to the lack of significant effects detected. For example Hamilton *et al* 2010 who conducted fish monitoring in the

Channel Islands MPA network (Case Study 8), mentioned spatial variation along with variation associated with sampling error are potential contributors to the lack of significant effects detected for some species. This statement was not supported with any analyses such as post-hoc power calculations, therefore it remains unknown if these non-significant effects have insufficient power or are truly non-significant effects.

The publication of negative results in marine ecology is a difficult task in itself (Underwood 1999). It will only be once scientists have demonstrated the credibility of their non-significant effects through reporting post-hoc power calculations that they will be able to contribute to the growing literature about MPA effects. Through demonstrating the credibility of non-significant, scientists will be able to contribute important scientific evidence that not all MPAs have strong effects on all species.

7.4 Reporting of results

There are four different reporting styles used to communicate monitoring results of the MPA monitoring programmes reviewed here, and these are: technical reports, scientific (peer reviewed) papers, reviews, and non-technical summary reports. Technical reports detailing results of monitoring programmes are generally published with a quick turnaround time (one to two years) from the final year of data collection to the year of publication. These generally have limited discussion and interpretation of results; however this is often intentional as monitoring results are also written up in scientific papers. Scientific papers contain much greater scientific detail and statistical analysis, but take substantially longer to publish, with the time lag between the final year of data collection to the year of publication being 3-5 years.

Based on the case studies reviewed here, there seems to be poor integration between science and management when it comes to the publication of MPA monitoring results. If technical reports are only used to report MPA monitoring results then it is almost certain that these will not contribute to the scientific knowledge of MPAs. This is likely to be in part due to the difficulties associated with accessing grey literature (as highlighted in recent reviews: Foden *et al* 2008, Stewart *et al* 2008). Additionally, most authors of scientific papers only cite scientific literature, as is the case for many recent MPA reviews (e.g. Claudet *et al* 2008, Lester *et al* 2009, Babcock *et al* 2010). This reflects the general scientific view that unless results are published in peer reviewed scientific journals, then the work is not scientifically credible (Lindenmayer & Likens 2010). This is a critical issue for two of the case studies in this review, the monitoring programmes in Victoria's MNPs and Jervis Bay MP in Australia, which to date have not had their long-term monitoring results published in any scientific papers.

By publishing monitoring results in scientific papers, scientists are contributing to the growing understanding of the effects of MPAs on marine communities. However, the level of scientific detail in scientific papers and the quest for authors to present novel ideas rather than standard monitoring results, means that managers can not as easily use these scientific results to inform their MPA conservation objectives. This dichotomy between the level of detail in technical reports and scientific papers can be seen when comparing the same monitoring results from the Florida Keys NMS fish monitoring programme which have been used to publish a technical report (Bohnsack *et al* 2009) compared to the more complex scientific papers (Ault *et al* 2006, Smith *et al* 2011). If there is a sole reliance on publishing scientific papers, then it is likely that the value of the results from the monitoring programme won't be maximised. This is because it can take be between 2-8 years before other scientists and managers become aware of the existence of a long-term monitoring programme.

There is great value in having different reporting styles such as technical reports, scientific papers and also contributions to large scale reviews, as the different levels of frequency of publication and level of scientific detail mean that both managers and scientists can benefit from the reporting of MPA monitoring results. All MPA monitoring programmes should therefore ensure that monitoring results are presented in all of these different reporting styles. As was highlighted in section 6.5, many of the other potential case studies considered for this review could not be included as the most recent reporting of results has occurred only in scientific papers which contain assessments of data which is over five years old. In addition to this, none of these potential case studies produce publicly available technical reports therefore the utility of monitoring results to the relevant MPA managing agencies must be limited.

For some of the MPA monitoring programmes reviewed here, non-technical summary reports are used to summarise results of MPA monitoring in order to assess the condition of an MPA. Non-technical summary reports exist for two MPAs reviewed here: the Great Barrier Reef MP in Australia (Great Barrier Reef Outlook Report, Great Barrier Reef Marine Park Authority 2009) and the Channel Islands MPA network in the USA (Channel Islands NMS Condition Report, Office of National Marine Sanctuaries 2009). These reports have been highlighted in the scientific literature as effective forms of communication to audiences beyond the scientific community (Grorud-Colvert *et al* 2010) and effective and standardised tools to assess overall environmental condition and to support adaptive management (McCook *et al* 2010). However, there can be issues with the providing evidence of data sources used to make condition assessments. For example it can be unclear to what degree expert judgement versus monitoring results has been used in final assessments. This is the case for Channel Islands NMS Condition Report (Office of National Marine Sanctuaries 2009), and the Report Card for the Mesoamerica Reef in South America (HRHP 2010). Nevertheless non-technical summary reports are advocated as being the key to ensuring monitoring results are translated into standard environmental assessments which are fed into adaptive management of protected areas (Stern 2006, Foden *et al* 2008, Leverington *et al* 2008, Grorud-Colvert *et al* 2010, McCook *et al* 2010). An obvious recommendation from this review is therefore that all MPA managing agencies should consider using non-technical summary reports to aid in their adaptive management and to ensure transparency of their management activities.

7.5 Other unexpected issues

There have been some unexpected issues encountered during this review which can help explain some of the issues with current monitoring programmes highlighted in this review.

Firstly, there are surprisingly few long-term monitoring programmes (greater than five years long) which have current data (up to five years old) presented in publicly available reports or papers - only eleven case studies were found out of over twenty MPAs (many with numerous monitoring programmes) which fit the criteria for this review.

The majority of the monitoring programmes considered in this review are conducted independently of the responsible MPA managing agencies. That is monitoring is done by scientists, either from academic institutions, government agencies or NGOs who are funded often completely independently of the MPA managing agency. This observation alone can help explain some of the issues highlighted in the review, such as the failure to link MPA conservation objectives and monitoring programme objectives, and the prominence of reporting results in scientific publications rather than technical and non-technical summary reports which are more relevant to managing agencies. If scientists remain independently funded, then long-term MPA monitoring programmes are likely to have different research focuses. Therefore there will be no incentive to address either of the above two issues. The lack of integration between managers and scientists involved in experimental marine ecology, EIA and MPA monitoring has been highlighted as a substantial barrier to effective marine environmental management in the past (Underwood 1998, Castilla 2000, Claudet & Pelletier 2004). However, many MPA scientists who were contacted during this review are very generous with their time spent with MPA managing agencies. But unless they are given the resource to make more formal links with MPA managing agencies then the current inadequate state of long-term MPA monitoring will remain unchanged.

Uncertainty in funding is a major threat to the continuation of long-term environmental monitoring programs (Stewart *et al* 2009, Lindenmayer & Likens 2010), and has been highlighted in some studies as the reason for reduced monitoring over some years (e.g. Smith *et al* 2011). The persistence of long-term monitoring programs can often be due to the dedication of an individual passionate scientist. This should not be the case for monitoring MPAs. The only way to ensure the continuation of long-term monitoring programs must be for MPA managing agencies to make a substantial contribution to monitoring programmes. Resource needs to be carefully considered, as funding is required for all aspects of monitoring from planning through to reporting

Finally, the success of some monitoring programmes seems to be vulnerable to the complex government jurisdiction of an MPA. For example, the Channel Islands National Marine Sanctuary (NMS) has 17 regulatory bodies, the military and one non-profit organization involved in its complex jurisdiction and management (Office of National Marine Sanctuaries 2009). The condition of the Channel Islands National Marine Sanctuary (NMS) is reported by the National Oceanic and Atmospheric Administration (NOAA), Office of National Marine Sanctuaries (Office of National Marine Sanctuaries 2009). The Channel Islands National Marine Sanctuary (NMS) is an extension of the state run Channel Islands MPA network (0 to 3 nautical miles) and covers waters from three to m nautical miles off-shore (National Oceanic and Atmospheric Administration 2011). Monitoring is only conducted within the Channel Islands MPA network (D. Kushner pers comm.) and monitoring results are compiled by the California Department of Fish and Game (GDFG) (California Department of Fish and Game 2008). NOAA uses the results from monitoring in the Channel Islands MPA network (near-shore) to assess the condition of the Channel Islands NMS (off-shore). To add to the complexity of this case study, neither NOAA or CDFG are involved in the primary monitoring programme of the Channel Islands MPA network. This is the Kelp Forest Monitoring program which is conducted by the National Park Service and Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO). Under this programme, some sites have been monitored for 30 years, however this dataset has only ever been partially analysed and reported (D Kushner pers comm.; most recent publication: Hamilton *et al* 2010). There appears to be some serious issues with the funding of this monitoring and particularly the dedication of resource towards the analysis and reporting of results. It seems that although NOAA and CDFG require the monitoring results of the Kelp Monitoring program, they do not fund this work in any way (D Kushner pers comm.). Such jurisdictional issues and again funding issues can leave a monitoring programme vulnerable to failure (Lindenmayer & Likens 2010).

8 Conclusion

As the establishment of MPAs around the world continues to rise (UNEP-WCMC 2008, Orbach & Karrer 2010), there is a need for monitoring programmes to provide scientific evidence of the effectiveness of MPAs in relation to marine biodiversity which MPAs aim to protect. Long-term monitoring programmes must be carefully planned and must embody the principles of a good monitoring framework in order to evaluate the effectiveness of MPAs in a scientifically credible way. The long-term MPA monitoring programmes reviewed in this report have highlighted that the principles of a good monitoring framework are not currently being met. Given the limited number of long-term MPA monitoring programmes around the world, this is very concerning.

This review has highlighted the following concerning issues with long-term MPA monitoring programmes:

- Currently all monitoring programmes fail to adequately state and link their hierarchy of key questions (MPA conservation objectives, monitoring programme objectives and hypotheses). Without clearly stated and linked questions, statistical analyses and interpretation of monitoring data will be meaningless and ineffective at providing management advice.
- The monitoring design and data collection methods used in MPA monitoring programmes are very similar to those used in EIA, therefore there should be more attention paid to the EIA literature which have dedicated discussions relating to monitoring design in the naturally variable marine environment.
- Many different types of statistical analysis are used in MPA monitoring programmes, the majority of which are scientifically valid. However, most scientists fail to adequately consider the pitfalls associated with statistical inference. Given the variety of statistical techniques seen in this review, scientists should dedicate more time to discussing appropriate statistical techniques to detect long-term changes in MPA datasets.
- A balance in reporting of results in technical reports, scientific papers and non-technical summary reports should be the focus of all MPA managing agencies and scientists. This in turn should help address the current lack of funding of monitoring programmes from MPA managing agencies.

This review has highlighted current monitoring approaches used in some of the most notable examples of long-term MPA monitoring programmes from around the world. The current issues with these monitoring programmes and lessons learned from other fields of marine and environmental research can be applied to all types of environmental monitoring. These lessons should help improve the scientific credibility and success of current and upcoming marine monitoring programmes.

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JNCC Report
No: 455

A global review of long-term Marine Protected Area monitoring programmes:
The application of a good framework to marine biological monitoring

VOLUME 2: APPENDIX 1 – 4

A report prepared for JNCC by:
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Table of Contents

APPENDIX 1: Case Studies 1 - 11

CASE STUDY 1: Long Term Monitoring Program, Great Barrier Reef Marine Park, Queensland, Australia

MPA: Great Barrier Reef Marine Park (MP), Queensland, Australia

Managing Agency: Great Barrier Reef Marine Park Authority (GBRMPA)

Park details
The Great Barrier Reef MP is a system of multiple use zones originally legislated in 1975 (but not fully implemented until 1989), and was recently re-zoned in 2004 which incorporated 'no-take' zones. In 2004 it was the world's largest network[1] of marine reserves, which protects 20% of the 70 identified bioregions within the MP (Great Barrier Reef Marine Park Authority 2009, National Biodiversity Strategy Review Task Group 2009). It extends over 2300km along the coast of Queensland and covers approximately 34,440,000 ha (Great Barrier Reef Marine Park Authority 2009), of which approximately 11,539,500 ha is no-take status (Wilkinson 2008).

MPA conservation objectives
To provide for the long term protection and conservation of the environment, biodiversity (including ecosystems, habitats, populations and genes) and heritage values of the Great Barrier Reef Region (Australian Government 2010).

Biological monitoring programmes
Many habitats and species are monitoring within the Great Barrier Reef MP (Great Barrier Reef Marine Park Authority 2009), and these include:
- Inshore and offshore coral reef communities (corals and other benthic invertebrates, algae and fish)
- Mangroves
- Seagrass
- Marine turtles
- Estuarine crocodiles
- Seabirds
- Whales

Monitoring Programme Case Study
Australian Institute of Marine Science (AIMS) Long Term Monitoring Program (LTMP) - coral reef benthic and fish communities (e.g. Sweatman *et al.* 2008).

Who monitors
AIMS scientists.

NB AIMS is a scientific research agency, whilst GBRMPA is the management agency for the Great Barrier Reef MP. This monitoring program was developed by AIMS scientists, independently of the need to demonstrate the effectiveness of the Great Barrier Reef MP (for GBRMPA) since it's re-zoning in 2004. Hence AIMS has a predominant interest in monitoring long-term changes within the MP, rather than demonstrating the effectiveness of protection (which is GBRMPA's aim). AIMS scientists provide 'situational awareness' to

[1] Two Pacific MPAs were launched in 2006 and now eclipse the GBR Marine Park in size: The Papahānaumokuākea Marine National Monument (35,689,300 ha) which includes the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve; and, the Phoenix Islands Protected Area (41,050,000 ha).

GBRMPA about how the reef is going in relation to threats to the Great Barrier Reef MP (H Sweatman pers comm.).

Primary contact
Dr Hugh Sweatman, Senior Research Scientist, AIMS

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the LTMP reports (Sweatman *et al.* 2008), however the authors do acknowledge how the LTMP contributes significantly to the GBRMPA's reporting on the status of the Great Barrier Reef MP.

Monitoring programme objectives
- To monitor the changes in distribution and abundance of reef biota on a large scale.
- To examine the effect of re-zoning the Great Barrier Reef MP on biodiversity.
- To address long term regional change in benthic assemblages, reef fishes and crown-of-thorn starfish on coral reefs in the Great Barrier Reef MP.

What is monitored
- Benthic coral reef communities (percentage cover of all identifiable benthic organisms) and reef fish.
- Other monitoring done (not covered in this case study): crown-of-thorns starfish, and coral mortality.

Scale of the monitoring program
Spatial: Intensive surveys of 46 - 56 reefs within 6 Sectors of the Great Barrier Reef MP (34,440,000 ha).

Temporal: Coral and fish monitoring has been conducted annually (alternative reefs surveyed every 2 years) since 1993.

Monitoring design
Spatial replication:
- Three or more Reefs within 6 Sectors are surveyed intensively across the 3 Subregions of the continental shelf (inshore, middle shelf and outer shelf).
- Three Sites are monitored within each Reef.
- Sampling units: five fixed 50 m transects are monitored within each site.

Temporal replication:
- Core reefs are surveyed annually (15 years to date), whilst a larger number of reefs are surveyed every second year.

Data collection method:
- Digital stills at 1 m intervals along each 50 m transect. Prior to 2007, video footage was taken of a 50cm wide swathe of each transects.
- Percent cover of corals and other benthic categories are estimated using a point sample: approximately 200 systematically-dispersed points are sampled from each photo transect. Hard and soft corals are identified to genus level and algae and all other benthic organisms are placed into functional groups.
- Fish are counted along the same 50m transects, with larger mobile fishes counted in a 5m wide belt transect and smaller damselfishes counted in a 1 m wide belt on the return swim along the transects.

Statistical analysis used

Assessment of temporal trends (form of trend):

- Linear mixed effect models are used to analyse temporal trends of mean values (over 5 transects) of % cover of the major benthic groups, major coral families, families of larger fish and Damselfish genera for each Sector and Sub-region (e.g. Cairns Sector, inshore sub-region) (**Figure 1-1**). The form of temporal trend (no trend, linear, quadratic, or smooth (non linear) trend) is determined by the model selection.
- The overall trend (over 13 annual surveys) and the current trend (between the two latest surveys) of hard coral cover, large fish and damselfishes (increasing, no change, decreasing) is summarised for each Sector to facilitate Great Barrier Reef MP wide comparisons (**Figure 1-2**).

Assessment of temporal trends (evaluation of trends at MPA and Reference sites):

- The effect of re-zoning (no-take vs open reef) was compared graphically (bar graph, using geometric means derived from mixed-effects models) for fish abundance data from 2006 (**Figure 1-3**). This monitoring will continue and temporal trends will be monitored from 2006 onwards (H. Sweatman pers comm.).

Results to date

A visual summary of trends for each benthic group within each Sector is presented in the Status Report 8 with more detailed results given for each Sub-region. A number of linear and non-linear temporal patterns have been detected for the benthic groups monitored and some patterns have been attributed to disturbance and recovery from crown-of-thorns starfish and cyclones.

Higher numbers of some fish species (e.g. coral trout) were found in no-take compared to open reefs following the 2004 re-zoning.

Higher level reporting of results (along with other monitoring programs from the Great Barrier Reef MP) has occurred in scientific papers (McCook *et al.* 2010) and in the Great Barrier Reef Outlook Report (Great Barrier Reef Marine Park Authority 2009) which assesses 'biodiversity' (through multiple habitat and groups of species indices), 'ecosystem health' (through multiple biological measures of ecosystem processes) and 'ecosystem resilience' (through multiple biological case studies of recovery from disturbance) of the Great Barrier Reef MP (see **Figure 1-4**). Information from coral monitoring feeds into 'biodiversity' (coral reefs considered as a habitat and corals, other invertebrates, macroalgae, and fish are considered as groups of species which indicate biodiversity), 'ecosystem health' (through measurements of reef building as an indicator of ecological processes) and 'ecosystem resilience' (recovery of coral reefs from disturbance (e.g. cyclones) and coral trout to closed fishing (no-take zones) as indicators of recovery after disturbance). Details on how the indices are assessed into classes is not specified.

Reporting style

Interpretation of monitoring data is presented in government technical/status reports (e.g. Sweatman *et al.* 2008), scientific papers (e.g. Russ *et al.* 2008, Sweatman 2008, Cheal *et al.* 2010, Osborne *et al.* 2011, Sweatman *et al.* 2011), non-technical summary reports (e.g. Great Barrier Reef Marine Park Authority 2009), and large scale reviews (e.g. Wilkinson 2008).

Reporting frequency and availability of reports

Eight Status reports have been produced for the Long-term Monitoring of the Great Barrier Reef MP and are available on the AIMS website.

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Cairns Sector

Inshore subregion

Trends in benthic organisms

In 2007 cover of hard coral increased on all intensive survey sites following a period of low coral cover around 2000 where the inshore reefs were exposed to cyclones, bleaching and COTS. Average cover of hard coral ranged from 7% at Green Is Reef to 26% at Fitzroy Is Reef. All the major hard coral families either increased or showed no recent change. There was no net change in soft coral cover over the survey period. In 2007 the average cover of algae was 56%.

Figure 4.11

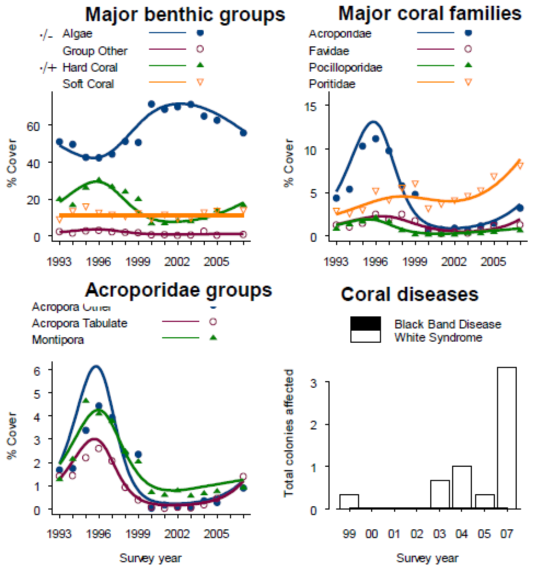

Figure 1-1. Linear mixed effect models used to analyse temporal trends of major benthic groups and fish (Source: Sweatman *et al.*, 2008, p.30)

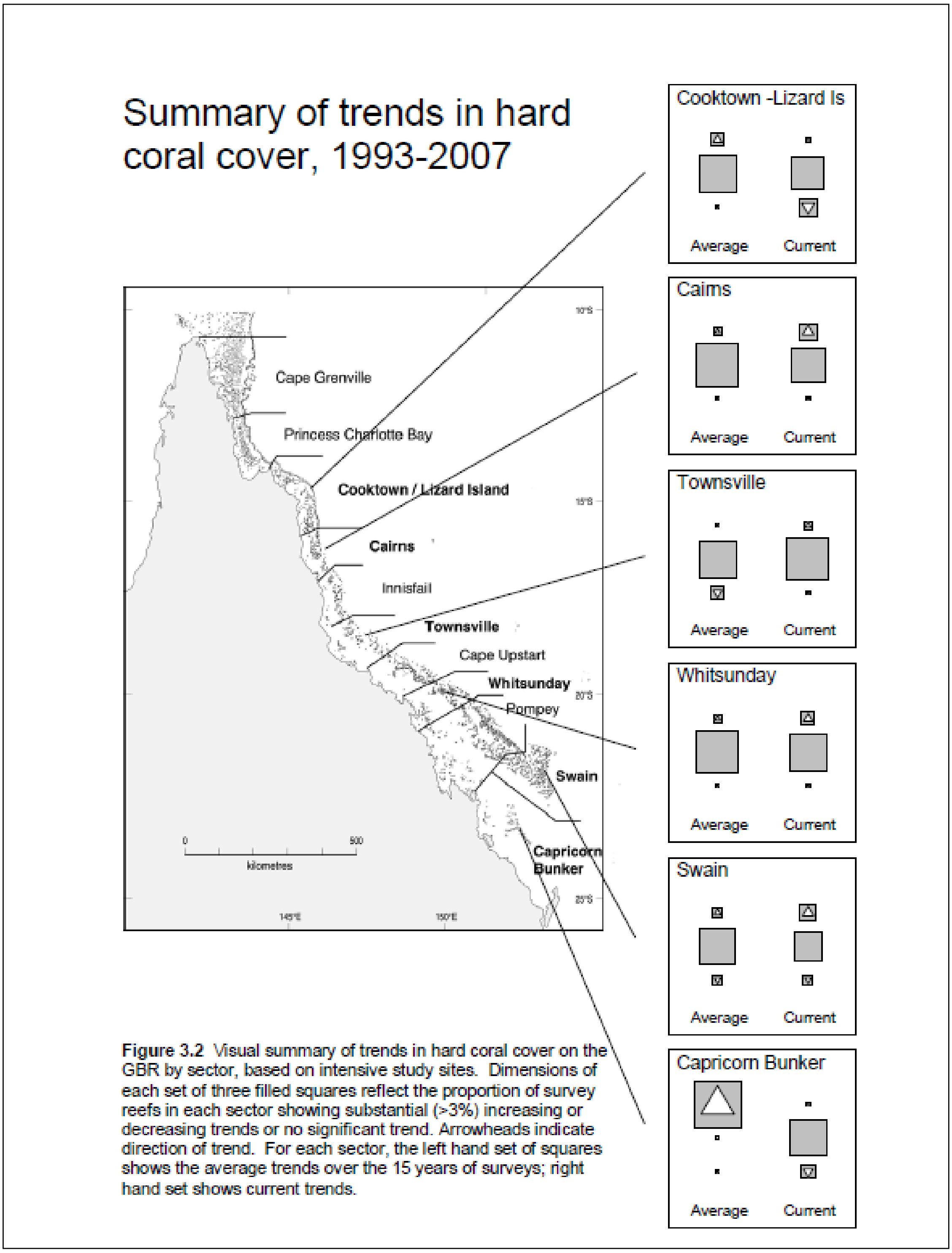

Figure 1-2. Summary of trends for each Sector of the Great Barrier Reef MP (Source: Sweatman *et al.*, 2008, p.16)

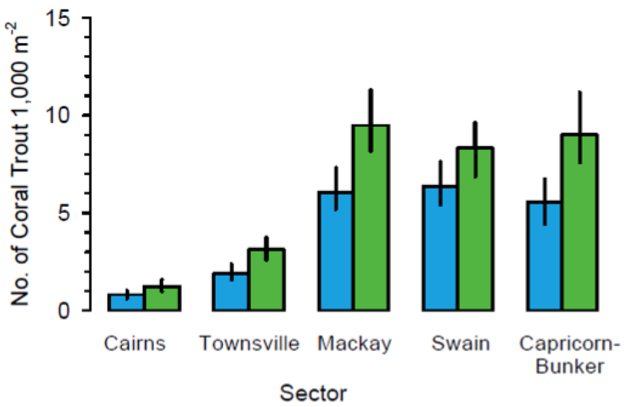

Figure 6.1 Numbers of coral trout (*Plectropomus* spp.) per 1,000 m^2 on No-take reefs (green bars) and Open reefs (blue bars) in five regions of the GBRMP in 2006. Values are geometric means (± 1 standard error) derived from mixed-effects models.

Figure 1-3. Comparison of fish abundance between ‘no-take’ and open reefs (Source: Sweatman *et al.*, 2008, p. 333).

2.4.2 Populations of species and groups of species

Assessment component	Summary	Assessment Grade: Very good	Good	Poor	Very poor
Mangroves	The Great Barrier Reef is maintaining strong mangrove biodiversity with local fluctuations, mainly along the developed coast.	●			
Seagrass	The Great Barrier Reef is maintaining seagrass biodiversity with local fluctuations in inshore waters.		●		
Macroalgae	The biodiversity of macroalgae is being maintained but there is little information about its condition.		?		
Benthic microalgae	Benthic microalgae are little studied, but they are believed to be in good condition.	?			
Corals	There are more than 500 species of corals, with localised declines in some hard corals and limited information about soft corals, sea pens and sea fans.		●		
Other invertebrates	Little is known about most non-commercial invertebrate species.	?			
Plankton and microbes	Little is known about the status of plankton or microbes on the Great Barrier Reef.	?			
Bony fish	Of the more than 1600 bony fish species, only a few are known to have locally depleted populations.		?		
Sharks and rays	There is concern about declines in populations of some of the 134 shark and ray species.			?	
Marine turtles	Five of the six species of marine turtle on the Great Barrier Reef have declined; the loggerhead, flatback and green turtle nesting populations appear to have stabilised or are now increasing.			○	
Sea snakes	There are 14 species of sea snake on the Great Barrier Reef and there are serious concerns about the status of some species.			?	
Estuarine crocodiles	Numbers of estuarine crocodiles are recovering following protection of the species.		●		
Seabirds	Twenty-two species of seabird breed on the Great Barrier Reef with serious declines in some populations.			○	
Whales	Most whales appear to be maintaining intact populations. Humpback whales are recovering strongly after being decimated by whaling.		●		
Dolphins	There is limited information about most dolphin populations; but two inshore dolphin species are known to be at risk.		?		
Populations of species and groups of species	Populations of almost all known Great Barrier Reef species or groups of species appear to be intact, but some populations such as dugongs, as well as some species of shark, seabirds and marine turtles, are known to have seriously declined, due mainly to human activities and declining environmental conditions. Many species are yet to be discovered and for many others, very little is known about their status. In time, more populations are likely to decline. Populations of some formally listed threatened species have stabilised but at very low numbers; other potentially threatened species continue to be identified.		◉		

GRADING STATEMENTS

- **Very good** - Available evidence indicates only a few, if any, populations of a species or group of species have declined.
- **Good** - Populations of a number of species have declined significantly.
- **Poor** - Populations of many species have declined significantly.
- **Very poor** - Populations of a large number of species have declined significantly.

Figure 1-4. Biodiversity assessment for the Great Barrier Reef Outlook Report based on biological indices (source: Great Barrier Reef Marine Park Authority, 2009, p. 32).

CASE STUDY 2: Reef Rescue Marine Monitoring Program, Great Barrier Reef Marine Park (MP), Queensland, Australia

MPA: Great Barrier Reef Marine Park (MP), Queensland, Australia

Managing Agency: Great Barrier Reef Marine Park Authority (GBRMPA)

Park details
See details in Case Study 1

MPA conservation objectives
See details in Case Study 1

Biological monitoring programmes
See details in Case Study 1

Monitoring Programme Case Study:
Reef Rescue Marine Monitoring Program (RRMMP) Intertidal Seagrass (McKenzie *et al.* 2001, McKenzie *et al.* 2010), which is a part of the long-term Water Quality and Ecosystem Monitoring Program in the Great Barrier Reef lagoon (Coles *et al.* 2007).

Who monitors
Fisheries Queensland/ Department of Employment, Economic Development and Innovation (DEEDI), James Cook University (JCU) and Seagrass Watch volunteers on behalf of Australian Government Department of the Environment, Water, Heritage and the Arts (DEWHA).

Primary contacts
Dr David Souter, Great Barrier Reef Program Research Manager, Reef and Rainforest Research Centre Limited

Len McKenzie, Principal Scientist, Fisheries Queensland (DEEDI)

Dr Rob Coles, Principal Scientist, Fisheries Queensland (DEEDI)

Acknowledgement MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the RRMMP reports (McKenzie *et al.* 2010). Instead seagrass beds are highlighted as important habitats in the Great Barrier Reef MP and monitoring of seagrass beds was established to provide an indication of coastal ecosystem health (Coles *et al.* 2007, McKenzie *et al.* 2010).

Monitoring programme objectives
- To understand the status and trend of Great Barrier Reef MP intertidal seagrass (detect long-term trends in seagrass abundance, community structure, distribution, reproductive health, and nutrient status from representative intertidal seagrass meadows),
- To identify response of seagrass to environmental drivers of change,

What is monitored
- Seagrass % cover & species composition
- Seed banks
- Epiphytes & macro-algae cover
- Meadow edge mapping
- Reproductive health
- Seagrass tissue elements (C:N:P)

- In-situ canopy temperature and light

Scale of the monitoring program
Spatial: Six large regions within the Great Barrier Reef MP where seagrass is most at risk (34,440,000 ha).

Temporal: Monitoring began in 1999, but at some regions monitoring began between 2002 and 2005.

Monitoring design
Spatial replication:
- Multiple locations are surveyed within each of the 6 Regions
- Two sites (50 x 50 m) are located within each location.
- Sampling units: three fixed 50m transects are surveyed at each site (using up to eleven 50x50cm quadrats placed at 5 m intervals along each transect).

Temporal replication:
- Bi-annual intertidal monitoring in late dry (September/October 2009) and late monsoon (March/April 2010) of each year.

Data collection method:
- Quadrats are used to collect information on seagrass cover, species composition, canopy height, macro-algae cover, epiphyte cover and macro-faunal abundance.
- The edge of seagrass beds are also mapped within 100m of the sites.
- Other data collected separately include: seagrass reproductive health data, seagrass tissue nutrients, within seagrass canopy temperature and seagrass canopy light.

Statistical analysis used
<u>Assessment of temporal trends (form of trend):</u>
- One-way ANOVA used to test the overall change over time in seagrass abundance at Great Barrier Reef MP level and this is supported by a time-series plot (**Figure 2-1**).
- Generalised temporal trends (relative to a 95th percentile of each site across all data) are plotted to assess changes in mean (± s.e.) values of seagrass abundance over habitats at the Great Barrier Reef MP level (**Figure 2-2**).

<u>Assessment of spatial differences:</u>
An overall Report Card status of seagrass (**Table 2-1 Report card for seagrass status within regions and for the GBR Marine Park (Source: McKenzie *et al.,*2010, p 16).** is based on four separate measures (seagrass abundance, seagrass reproductive effort, seagrass environment nutrient status, seagrass environment light availability) and is represented by five levels of status (Poor, Fair, Moderate, Good, Excellent). This considers regional differences based on the most recent year of data (not the entire temporal data-set).

Results to date
There have been downward trends in seagrass abundance and the overall status of intertidal seagrass meadows within the Great Barrier Reef MP are considered to be in a fair state (McKenzie *et al.* 2010).

Higher level reporting of results (along with other monitoring programs from the Great Barrier Reef MP) has occurred in scientific papers (McCook *et al.* 2010) and in the Great Barrier Reef Outlook Report (Great Barrier Reef Marine Park Authority 2009) which assesses 'biodiversity' (through multiple habitat and groups of species indices), 'ecosystem health' (through multiple biological measures of ecosystem processes) and 'ecosystem resilience (through multiple biological case studies of recovery from disturbance) of the GBR (see

Figure 1-4 in Case Study 1). Information from seagrass monitoring feeds into 'biodiversity' (considered as a habitat and a group of species as indicators of biodiversity), and 'ecosystem health' (through measurements of canopy light as an indicator of sedimentation) assessments.

Reporting style
Interpretation of monitoring data is presented in government technical/status reports (e.g. Coles *et al.* 2007, McKenzie *et al.* 2010), scientific papers (e.g. Coles *et al.* 2009) and non-technical summary reports (e.g. Great Barrier Reef Marine Park Authority 2009).

Reporting frequency and availability of reports
Annual scientific reports are produced and are available on the Seagrass Watch website.

References
Coles R, McKenzie L, De'ath G, Roelofs A, Long WL (2009) Spatial distribution of deepwater seagrass in the inter-reef lagoon of the Great Barrier Reef World Heritage Area. Marine Ecology-Progress Series 392:57-68

Coles RG, McKenzie LJ, Rasheed MA, Mellors JE, Taylor H, Dew K, McKenna S, Sankey TL, Carter AB, Grech A (2007) Status and trends of seagrass habitats in the Great Barrier Reef World Heritage Area. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns. 122 pp. http://www.seagrasswatch.org/Info_centre/Publications/113_QDPI_Coles_et_al_2007_Status_and_Trends.pdf

Great Barrier Reef Marine Park Authority (2009) Great Barrier Reef outlook report 2009. Great Barrier Reef Marine Park Authority, Australian Government. http://www.gbrmpa.gov.au/corp_site/about_us/great_barrier_reef_outlook_report

McCook LJ, Ayling T, Cappo M, Choat JH, Evans RD, De Freitas DM, Heupel M, Hughes TP, Jones GP, Mapstone B, Marsh H, Mills M, Molloy FJ, Pitcher CR, Pressey RL, Russ GR, Sutton S, Sweatman H, Tobin R, Wachenfeld DR, Williamson DH (2010) Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves. Proceedings of the National Academy of Sciences of the United States of America 107:18278-18285

McKenzie LJ, Campbell SJ, Roder SJ (2001) Seagrass-Watch maual for mapping and monitoring seagrass resources by community (citizen) volunteers. QF, NFC, Cairns. 100 pp. http://www.seagrasswatch.org/Methods/Manuals/SeagrassWatch_monitoring_guidelines_2ndEdition.pdf

McKenzie LJ, Unsworth RKF, Waycott M (2010) Reef Rescue Marine Monitoring Program: Intertidal Seagrass, Annual Report for the sampling period 1st September 2009 – 31st May 2010. . Fisheries Queensland, Cairns. 136 pp. http://www.gbrmpa.gov.au/__data/assets/pdf_file/0008/46529/Seagrass_final_annual_report_2009_10.pdf

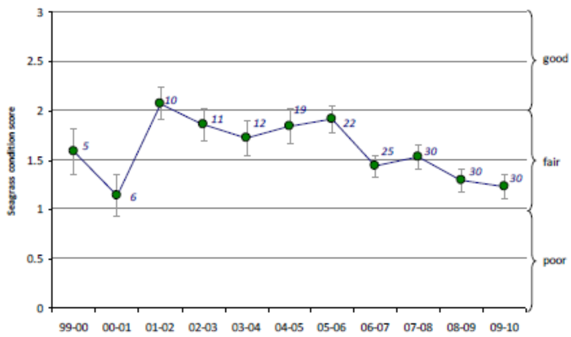

Figure 3. *Average abundance score (all sites and seasons pooled) for each monitoring period in the GBR (±Standard Error).*

Figure 2-1. Time-series plot to support the one-way ANOVA which demonstrates a significant decline in seagrass abundance over time at the GBR Marine Park level (Source: McKenzie *et al.*, 2010, p 17).

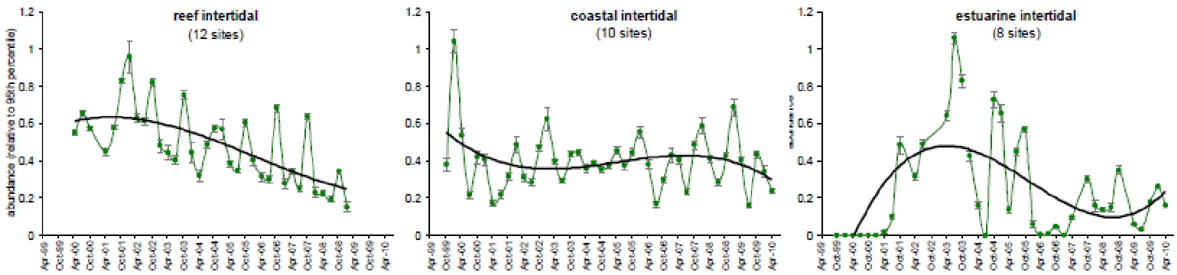

Figure 4. *Generalised trends in seagrass abundance for each habitat type (sites pooled) relative to the 95th percentile (equally scaled). The 95th percentile is calculated for each site across all data.*

Figure 2-2. Generalised temporal trends of seagrass cover over different habitat types summarised at the GBR Marine Park level (Source: McKenzie *et al.*, 2010, p 17).

Table 2-1 Report card for seagrass status within regions and for the GBR Marine Park (Source: McKenzie *et al.*,2010, p 16).

Table 11. *Report card for seagrass status (community & environment) for the GBR and each NRM region: Sept 2009 – May 2010. Values are indexed scores scaled from 0-100. Green = good, yellow = moderate, gold = fair, red = poor.*

Region	Seagrass Abundance	Reproductive Effort	Nutrient Status (C:P & N:P ratios)	Light availability (C:N ratio)	**Seagrass Index**
Cape York	58	67	33	33	**48**
Wet Tropics	50	0	33	33	**29**
Burdekin	12	33	67	33	**36**
Mackay Whitsunday	31	0	33	33	**24**
Fitzroy	52	33	33	67	**46**
Burnett Mary	31	0	33	33	**24**
GBR	39	38	38	35	37

CASE STUDY 3: Subtidal Reef Monitoring Program, Victoria's Marine National Parks and Sanctuaries, Victoria, Australia

MPA: Victoria's Marine National Parks (MNPs) and Sanctuaries (MSs), Victoria, Australia

Managing Agency: Parks Victoria

Park details
In 2002 the Victorian government established a system of 13 MNPs and 11 smaller MSs which protect 5.3% of Victoria's coastal waters (Power & Boxshall 2007). The MNPs and MSs are highly protected, "no-take" areas where no fishing, extractive or damaging activities are allowed. Recreation, tourism, education and research are encouraged (Power & Boxshall 2007).

MPA conservation objectives
Victoria's MNPs and MSs were chosen to be representative of the diversity of Victoria's marine environment (Power & Boxshall 2007), with the main conservation objective to "*maintain biodiversity and natural processes"* (Victorian Government 2004, Power & Boxshall 2007).

Biological monitoring programmes
- Subtidal rocky reef assemblages (algae, invertebrates and fish)
- Intertidal rocky reef assemblages (algae, invertebrates)

<u>Monitoring Programme Case Study</u>
Subtidal Reef Monitoring Program (SRMP) (Edmunds & Hart 2003) - Subtidal rocky reef assemblages (algae, invertebrates and fish). Details of the remainder of the case study are based on the most recent report from the SRMP - The Reef Biota at Port Phillip Heads MNP (Edmunds *et al.* 2010).

Who monitors
Australian Marine Ecology (consultants to Parks Victoria)

Primary contact
Steffan Howe, Manager Marine Science, Parks Victoria

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the SRMP technical reports. However, the authors explain that Victoria's shallow reefs are a very important component of the marine environment because of their "high biological complexity, species diversity and productivity" (Edmunds *et al.* 2010), implying their utility in being an indicator of overall biodiversity and natural processes.

Monitoring programme objectives
- To compare changes in the status of species populations and biological communities between highly protected MNPs and MSs and other Victorian reef areas.
- To determine associations between species, and between species and environmental parameters (*e.g.* Depth, exposure, reef topography), and to assess how these associations vary through space and time.

What is monitored
- Subtidal rocky reefs communities (fish, algae and invertebrates) at 5-7m depth.

APPENDIX 1 - CASE STUDY 3: Subtidal Reef Monitoring Program, Victoria's Marine National Parks and Sanctuaries, Victoria, Australia

Scale of the monitoring program
Spatial: The SRMP covers 17 MNPs/MSs and corresponding reference sites which span the 2000km long Victorian coastline have been monitored since 2003/2004. 18 reef sites are surveyed (9 within the 'MPA' and 9 outside 'reference' sites) for the SRMP for Port Phillip Heads Marine National Park (PPHMNP) (3,580 ha).

Temporal: Four of the 17 MNPs (including PPHMNP) have been monitored since 1998 (prior to 2002 Victorian Marine Parks implementation).

Monitoring design
Spatial replication:
SRMP of PPHMNP

- 9 reef sites within the MPA and 9 Reference sites.
- Sampling unit: at each reef, one fixed 200m long transect (split into four 50 m replicate units) is surveyed.

Temporal replication:

- Bi-annual surveys 1998-2000, annual surveys: 2001-2004, 2006, 2009.

Data collection method:
Underwater visual census (using SCUBA divers) of:

- Fish are counted (in size classes) within 5 m of each side of the transect (a total of four 10 x 50 m sections of the 200 m transect are assessed for mobile fish at each site).
- Megafaunal invertebrates counted within 1 m of one side of the transect (a total of four 1 x 50 m sections).
- Macroalgae cover is estimated using 0.25 m^2 quadrat (with a grid of 7x7 perpendicular wires; i.e. 50 points) at 10 m intervals along the transect.
- Macrocystis angustifolia (kelp) is counted within 5 m of the transect, for each 10 m section of the transect.

Presentation and statistical analysis of data
All analysis are done separately for each set of sites associated with a single MNP/MS and corresponding Reference sites (ie Victoria wide evaluation has not been done to date):

Assessment of temporal trends (evaluation of trends at MPA and Reference sites):

- MDS plots (based on Bray-Curtis dissimilarity coefficient of log transformed data) are used to display the community structure (algal, invertebrates and fish communities) of all reefs within each MPA and Reference site (See **Figure 3-1**).
- Species diversity (using the reciprocal of Simpson's index), and abundance and cover of some algal, invertebrate and fish species (justification for choice not explained) is plotted over time, with an average trend for the MNP and Reference (see **Figure 3-2**).
- Size frequencies of some fish are compared between 2006 and 2009.

Results to date

- There has been very little interpretation of results in the technical reports to date.
- A review of the existing biological sampling data (Keough & Carnell in press) has analysed data to date, and found a limited number of significant effects of the MPAs. It is suggested that there is still a limited time-series of data to detect differences (despite the longest programs running for ten years), and given that there are no strong pressures (e.g. fisheries) surrounding the MNPs it may be that strong effects (such as those seen in Tasmania) may not occur in Victoria (Keough and Carnell, in press).
- There has been some criticism of the design of the SRMP, as the 4x50m transects are not independent (i.e. they are a part of the one 200m long transect) (Keough *et al.* 2007).

APPENDIX 1 - CASE STUDY 3: Subtidal Reef Monitoring Program, Victoria's Marine National Parks and Sanctuaries, Victoria, Australia

Reporting style

Interpretation of monitoring data is presented in government technical/status reports (e.g. Edmunds *et al.* 2010), but not in scientific papers or non-technical summary reports.

Reporting frequency and availability of reports

SRMP technical reports have been produced following each year of monitoring and are available on the Parks Victoria website.

References

Edmunds M, Hart S (2003) Parks Victoria Standard Operating Procedure: Biological Monitoring of Subtidal Reefs. Parks Victoria, Melbourne. http://www.parkweb.vic.gov.au/resources/19_1075.pdf

Edmunds M, Stewart K, Pritchard K (2010) Victorian Subtidal Reef Monitoring Program: The Reef Biota at Port Phillip Heads Marine National Park. Volume 4. Parks Victoria Technical Series No. 63. Parks Victoria, Melbourne. 107 pp. http://www.parkweb.vic.gov.au/resources/19_2620.pdf

Keough MJ, Carnell PE (in press) Ecological performance measures for Victorian Marine Protected Areas: Review of the existing biological sampling data. Parks Victoria, Melbourne.

Keough MJ, Ross DJ, Knott NA (2007) Ecological performance measures for Victorian Marine Protected Areas: Review of existing biological sampling program. Parks Victoria Technical Series No.51. Parks Victoria, Melbourne. http://www.parkweb.vic.gov.au/resources/19_2094.pdf

Power B, Boxshall A (2007) Marine National Park and Sanctuary Monitoring Plan 2007-2012. Parks Victoria, Melbourne. 104 pp. http://www.parkweb.vic.gov.au/resources/19_2097.pdf

Victorian Government (2004) National Parks Act 1975. Version No. 093. Act No. 8702/1975. Version incorporating amendments as at 17 June 2004. http://www.parkweb.vic.gov.au/resources/14_1157.pdf

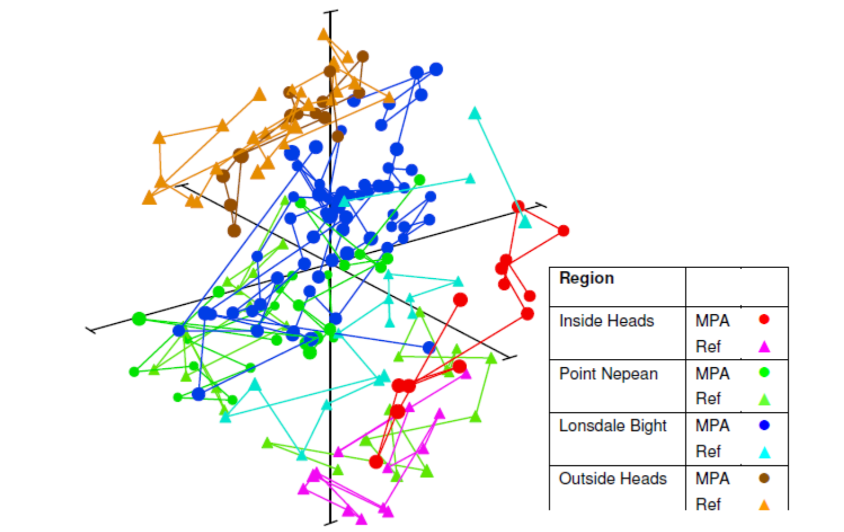

Figure 3.1. Three-dimensional MDS plot of algal assemblage structure for all Port Phillip Heads sites. Kruskal Stress value = 0.16.

Figure 3-1. MDS plot of algal assemblage structure for Regions and MPA or Reference sites over time (Source: Edmunds *et al.*, 2010, p22).

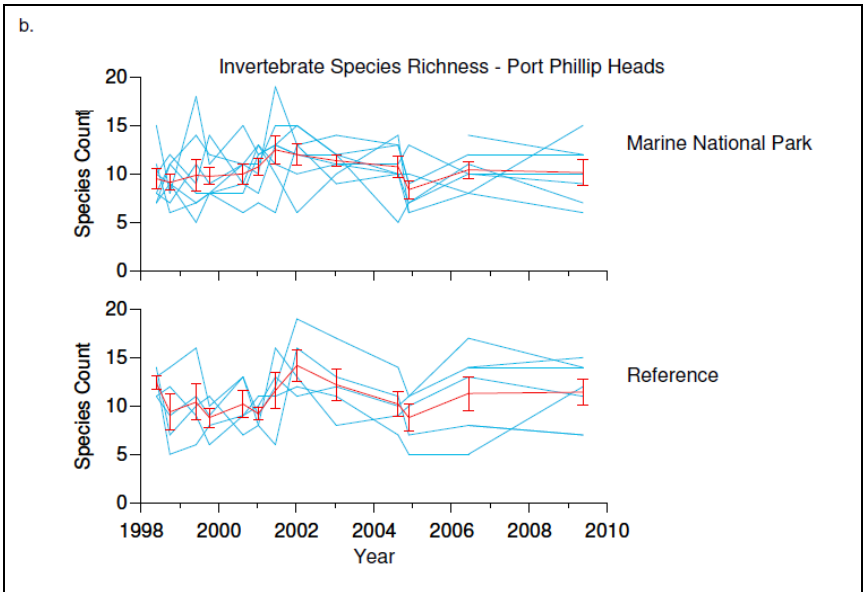

Figure 3.13. Trends in species richness of invertebrates at: (a) Popes Eye and South Channel Fort; and (b) Port Phillip Heads.

Figure 3-2. Temporal trends of species richness in individual sites, with an average trend (± s.e – assumed, as not stated) for the Marine National Park and Reference (Source: Edmunds *et al.*, 2010, p31).

CASE STUDY 4: Intertidal Reef Monitoring Program, Victoria's Marine National Parks and Sanctuaries, Victoria, Australia

MPA: Victoria's Marine National Parks (MNPs) and Sanctuaries, Victoria, Australia

Managing Agency: Parks Victoria

Park details
See details in Case Study 3

MPA conservation objectives
See details in Case Study 3

Biological monitoring programmes
See details in Case Study 3

Monitoring Programme Case Study
Intertidal Reef Monitoring Program (IRMP), using the most recent report (The Reef Biota at Central Victoria's MPAs; Edmunds *et al.* 2010) to provide details for the remainder of the case study.

Who monitors
Australian Marine Ecology (consultants to Parks Victoria)

Primary contact
Steffan Howe, Manager Marine Science, Parks Victoria

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the SRMP technical reports. However the authors explain that assessing the condition of an ecosystem over time, combined with an understanding of ecosystem processes, will allow improved management of threats or pressures and thus ensure ecosystem sustainability.

Monitoring programme objectives
To provide information on the status of Victoria's reef flora and fauna. This includes monitoring the nature and magnitude of trends in species abundances, species diversity and community structure.

What is monitored
- Intertidal rocky reef assemblages (algae and invertebrates)

Scale of the monitoring program
Spatial: Nine MNPs or Sanctuaries and corresponding Reference sites in the Central Victorian region (Total protected area: 10,813 ha, which ranges from Barwon Heads Marine Sanctuary (17 ha) to Port Phillip Heads Marine National Park (3,580 ha)).

Temporal: Monitored since 2003 (1 year after 2002 Victorian Marine Parks implementation).

Monitoring design
Spatial replication:
- 9 MPAs and corresponding Reference sites.
- At each site, one reef is surveyed.

- Sampling units: a series of 5 fixed transects (parallel positions equal distances apart, from high to low shore (i.e. transect length is variable)) are arranged along the shore (30-100 m), with 5 quadrats surveyed along each transect.

Temporal replication:
- Repeated monitoring every 1-2 years (2003, 2004, 2004/05, 2005/06, 2007 and 2009).

Data collection method:
- Five 50 x 50 cm quadrats (with a grid of 7x7 perpendicular wires; i.e. 50 points) placed systematically along each transect (although location is random within a 2x2 m area) used to estimate the abundance of mobile invertebrates and the percentage cover of sessile invertebrates and algae.
- The size of common snails and limpets are also measured.

Statistical analysis used
Assessment of temporal trends (evaluation of trends at MPA and Reference sites):
- Temporal trends of mean species diversity (using the reciprocal of Simpson's index), and species richness (counts) at site level are plotted (based on average values with no error bars) (see **Figure 4-1**).
- MDS plots (based on Bray-Curtis dissimilarity coefficient of log transformed data) are used to display the community structure (algal and sessile invertebrate assemblages combined, and mobile invertebrate assemblages) of all reefs within each MPA and Reference site (see **Figure 4-2**).
- Temporal trends in the mean size (±s.e.) of limpets and snails are plotted for each site (see **Figure 4-3**).

Results to date
- Only visual assessment of temporal and spatial trends has been discussed to date, with no explicit effects discussed.

Reporting style
Government technical/status reports (e.g. Edmunds *et al.* 2010), no scientific papers or non-technical summary reports.

Reporting frequency and availability of reports
IRMP technical reports have been produced following each year of monitoring for each Marine Park and Sanctuary are available on the Parks Victoria website.

References
Edmunds M, Stewart K, Pritchard K, Zavalas R (2010) Victorian Intertidal Reef Monitoring Program: The reef biota of central Victoria's marine protected areas. Volume 3. Parks Victoria Technical Series No.61. Parks Victoria, Melbourne. 117 pp. http://www.parkweb.vic.gov.au/resources/19_2618.pdf

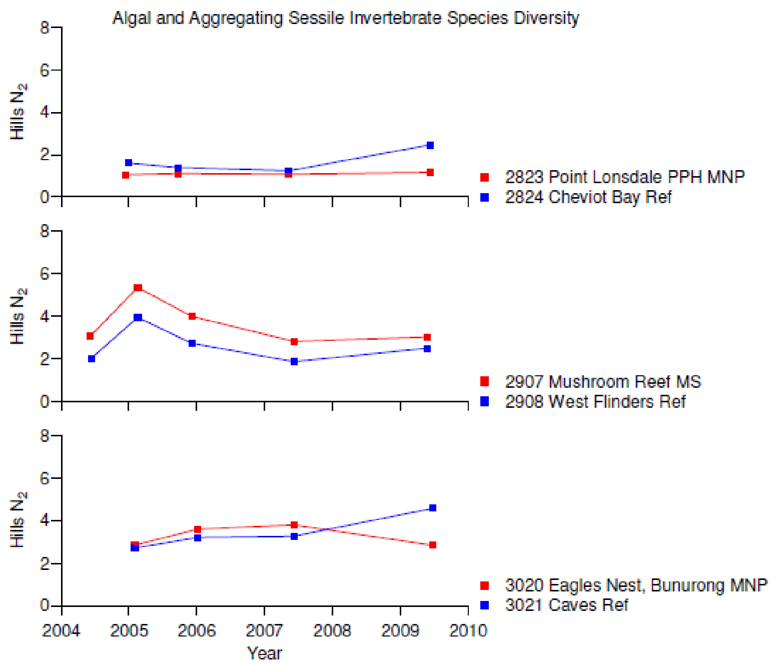

Figure 3.2. Algal and aggregating sessile invertebrate diversity (Hills N_2) of intertidal sites along the eastern central Victorian coast.

Figure 4-1. Temporal trends of average species richness in individual Marine National Park and Reference sites (source: Edmunds *et al.*, 2010, p21).

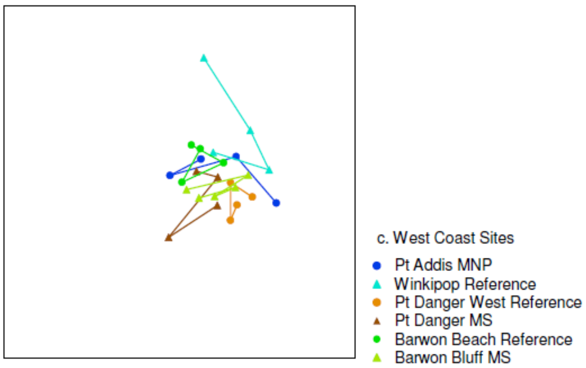

Figure 3.7. Two dimensional MDS plot of algal and sessile invertebrate assemblages on intertidal reefs in (a) northern Port Phillip Bay; (b) Port Phillip Heads and the eastern Victorian coastline; and (c) western Victorian coastline. Lines connect sites examined during consecutive surveys. Kruskal stress = 0.20.

Figure 4-2. MDS plot of algal and sessile invertebrate assemblage structure MPA or Reference sites over time (Source: Edmunds *et al.*, 2010, p22).

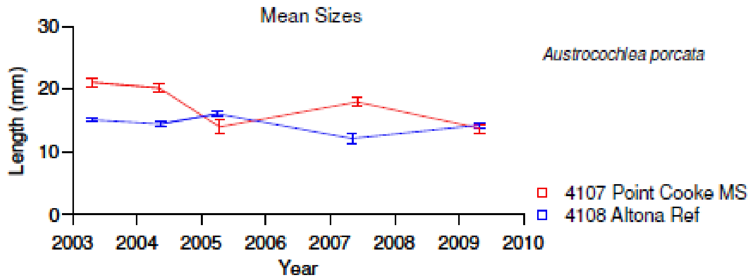

Figure 4.3. Mean sizes (± 95% confidence intervals) of *Austrocochlea porcata* at the Point Cooke Marine Sanctuary and the Altona reference site.

Figure 4-3. Plot of mean size of a common snail between a MPA or Reference site over time (source: Edmunds *et al.*, 2010, p36)

CASE STUDY 5: Ecosystem Monitoring, Tasmania's Marine Reserves, Tasmania, Australia

MPA: Tasmania's Marine Reserves (MRs), Tasmania, Australia

Managing Agency: Department of Primary Industries, Parks, Water and Environment (DPIPWE)

Park details
Tasmania has a system of seven "no-take" MRs located around its 5,400 km coastline. The MRs were established in 1991 (Governor Island, Ninepin Point, Tinderbox, and Maria Island), 2000 (Macquarie Island Marine Reserve), and 2005 (The Kent Group and Port Davey Marine Reserve) (Department of Primary Industries Water and Environment 2000, Parks and Wildlife Service Tasmania 2009).

MPA conservation objectives
To establish and manage a comprehensive, adequate and representative system of MPAs, to contribute to the long-term ecological viability of marine and estuarine systems, to maintain ecological processes and systems, and to protect Tasmania's biological diversity (Department of Primary Industries Water and Environment 2000).

Biological monitoring programmes
- Subtidal rocky assemblages (algae and invertebrates)

Monitoring Programme Case Study
Ecosystem monitoring (EM) of subtidal reefs in Tasmania's Marine Reserves (e.g. Barrett *et al.* 2009).

NB: This is an ongoing monitoring project which has been reported in a number of scientific publications and government technical reports, which report on a variety of scientific questions of interest and species (subtidal rocky reefs fish, algae and invertebrates).

Who monitors
Tasmanian Aquaculture and Fisheries Institute (TAFI) scientists

Primary contact
Dr Neville Barrett, Research Group Leader Marine Biodiversity, TAFI

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the scientific publications which relate to the Ecosystem monitoring (EM) of subtidal reefs (Barrett *et al.* 2009). However, the authors acknowledge of the general aim of all MPAs in Australia to "ensure long-term sustainability of coastal ecosystems" (Barrett *et al.* 2009).

Monitoring programme objectives
To determine if there were any identifiable effects associated with the removal of fishing pressure within reserves on target species or the broader ecosystem over this ecologically significant timescale (one decade).

What is monitored
- Subtidal rocky reefs communities (algae and invertebrates) at 5 m depth.

APPENDIX 1 - CASE STUDY 5: Ecosystem Monitoring, Tasmania's Marine Reserves, Tasmania, Australia

Scale of the monitoring program

Spatial: Four of Tasmania's eastern coast Marine Reserves and associated Reference sites (Total protected area is 2,436 ha, ranging from Governor Island (60 ha) to Maria Island (1,500 ha); Department of Primary Industries Parks Water and Environment 2011).

Temporal: Annual surveys from 1993-2002 (Barrett *et al.* 2009), which have been continued annually since 2002 and another decade of results will be published after 2012 (N. Barrett pers comm.). All 4 MRs were declared in 1991.

Monitoring design

Spatial replication:

- Four no-take and restricted-take zones (MPAs) compared to open zones (reference).
- Within each zone, multiple reefs are monitored.
- Sampling unit: at each reef a 200 m long transect (split into four 50 m units) is surveyed.

Temporal replication:

- Annually (for most years), with additional "Autumn" surveys and September for "Spring" surveys in 1992, 1993 and 1997.

Data collection method:

Underwater visual census (using SCUBA divers) of:

- Megafaunal invertebrates within 1 m of one side of the transect (a total of four 1 x 50 m sections).
- The cover of macroalgae is estimated using 0.25 m^2 quadrat (with a grid of 7x7 perpendicular wires; i.e. 50 points) at 10 m intervals along the transect line.

Statistical analysis used

<u>Assessment of temporal trends (evaluation of trends at MPA and Reference sites):</u>

- Temporal trends (mean ± standard error) are plotted for invertebrate and algal species and broader species groupings, species richness (both exploited and other species showing trends) (see **Figure 5-1**).
- The serial convergence or divergence between sites was tested using two-tailed critical values of the Spearman rank correlation coefficients (rs).
- The size of the commonly exploited lobster and abalone (proportion of 3 size classes) was plotted for each year (see **Figure 5-2**), but no statistical analysis done.
- MDS and SIMPER were used to investigate spatial and temporal differences of invertebrate and algal communities (see **Figure 5-3**).

Results to date

Barrett et al. (2009) gives the most overall view of monitoring to date (up to 2002). The ten years of monitoring since the MPA declaration has shown differences (not always positive) in population characteristics of many species (e.g. rock lobsters, urchins and abalone). Results were spatially variable with the two smaller MPAs showing fewer effects.

Reporting style

Monitoring results have been presented primarily in scientific papers (e.g. Barrett *et al.* 2009) and also government technical/status reports (e.g. Barrett *et al.* 2006). There are no non-technical summary reports. Also, data from this monitoring programme has contributed to a recent review (Babcock *et al.* 2010).

Reporting frequency and availability of reports

Infrequent scientific papers, with N. Barrett aiming to publish long-term monitoring results approximately every decade (N. Barrett per comm.). Some technical reports are available on the TAFI website, however others are not listed on the TAFI website and therefore are not all publicly available.

References

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Barrett NS, Buxton CD, Edgar GJ (2009) Changes in invertebrate and macroalgal populations in Tasmanian marine reserves in the decade following protection Journal of Experimental Marine Biology and Ecology 370:104-119

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Department of Primary Industries Water and Environment (2000) Tasmanian Marine Protected Areas Strategy. Department of Primary Industries Water and Environment, Tasmania. 28 pp. http://www.dpiw.tas.gov.au/inter,nsf/Attachments/BHAN-5498CT?open

Parks and Wildlife Service Tasmania (2009) Visitor's Guide to Tasmania's Marine Reserves. http://www.parks.tas.gov.au/index.aspx?base=397. Date cited: 28 February 2011

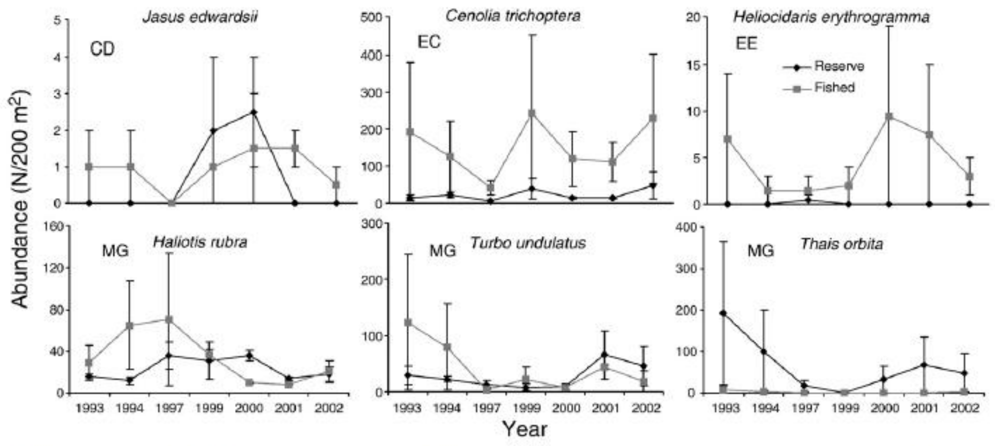

Fig 5. Mean abundance per site (± SE) of mobile macro-invertebrates within the Governor I marine reserve and at fished reference sites between 1992 and 2002. Species code key is given in Fig. 2 caption.

Figure 5-1. Temporal trends of key species (Source: Barrett *et al.*, 2009), p.108)

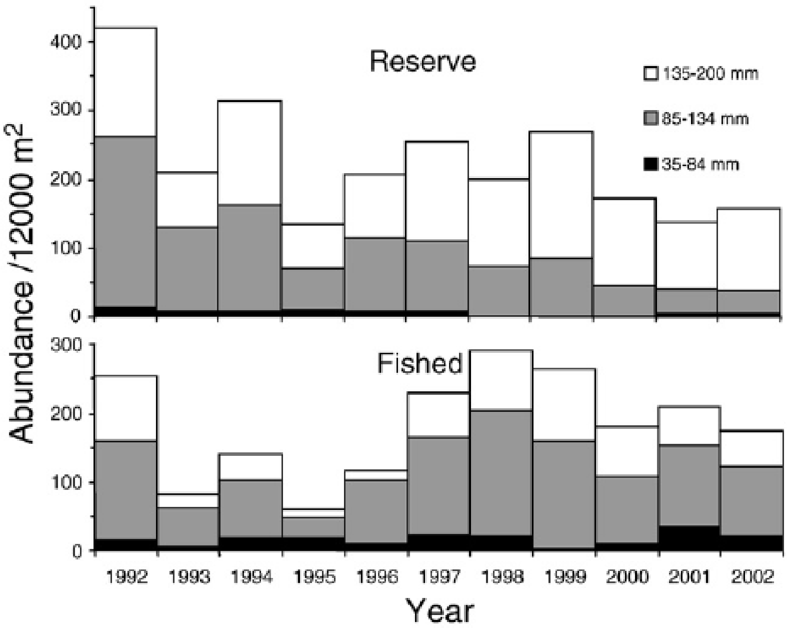

Fig. 6. Abundance per size category (shell length) of *Haliotis rubra* within the Maria I Marine Reserve and at fished reference sites between 1992 and 2002. The minimum legal size for abalone was 132 mm shell length.

Figure 5-2. The size of a commonly exploited abalone (proportion of 3 size classes) plotted over years (source: Barrett *et al.*, 2009, p. 110).

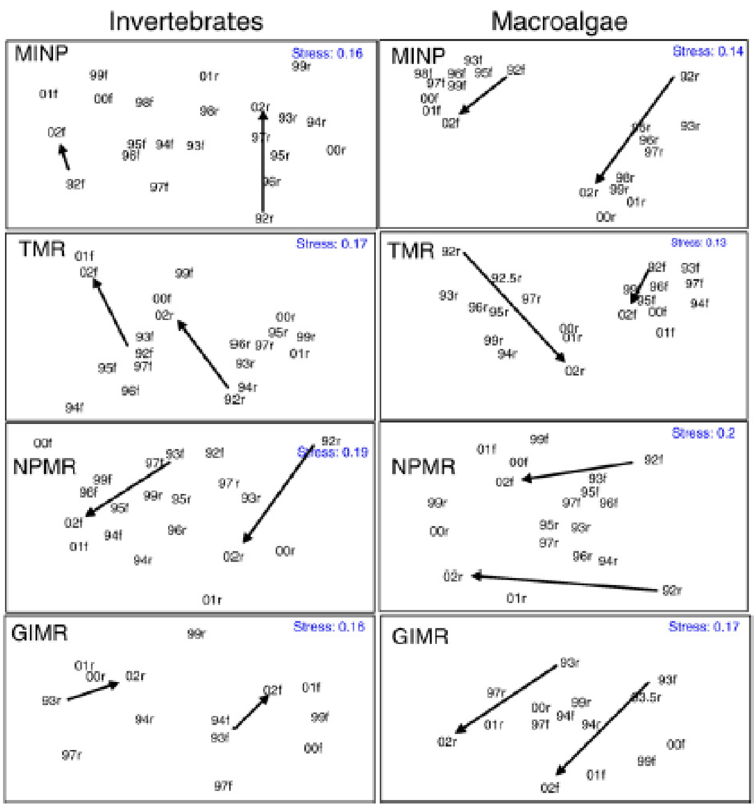

Fig. 14 MDS plots of the similarity between mobile invertebrate and macroalgal assemblages present during autumn within the Maria I (MINP), Tinderbox (TMR), Ninepin Point (NPMR) and Governor I (GIMR) marine reserves and at their respective fished reference sites between 1992 and 2002. Reserve assemblages are denoted by the suffix 'r', fished assemblages by 'f'. Arrows depict overall differences between initial and final assemblages.

Figure 5-3. MDS plots of invertebrate and algal assemblages showing shifts in space and time (source: Barrett *et al.*, 2009, p115).

CASE STUDY 6: Ecosystem Monitoring, New South Wales Marine Parks, Australia

MPA: New South Wales (NSW) Marine Parks (MPs), Australia

Managing Agency: NSW Marine Parks Authority (NSW MPA)

Park details
The NSW system of marine protected areas encompasses six multiple use MPs, 12 aquatic reserves and 62 national parks and reserves with marine components (NSW Marine Parks Authority 2011b). The six MPs comprise of "no-take" zones, and zones for other activities such as recreational and commercial fishing, diving, boating, snorkelling and tourism. These cover a total area of approximately 346,200 ha (ranging from Jervis Bay MP (21,000 ha) to Port Stephens–Great Lakes MP (98,000 ha); NSW Marine Parks Authority 2011b). The earliest MPs were established in 1998 (Jervis Bay MP and Solitary Islands MP), with the newest MP established in 2005 (Port Stephens–Great Lakes MP) (NSW Marine Parks Authority 2011b).

MPA conservation objectives
To protect and conserve the biological diversity and maintain ecological processes in marine parks (Marine Parks Act 1997; NSW Government 2007).

Biological monitoring programmes
Many research projects (both monitoring and experimental) are conducted by the NSW MPA and associated university researchers (predominantly on an individual park basis). e.g. Jervis Bay MP (NSW Marine Parks Authority 2011a)
- Shallow rocky reef algae, invertebrates and fishes
- Deep reef fish
- Rocky intertidal sessile invertebrates, mobile invertebrates and macroalgae
- Seagrass
- Estuarine invertebrates, algae, fish
- Soft-sediment invertebrate and fish communities
- Demersal sharks and rays

<u>Monitoring Programme Case Study</u>
Ecosystem monitoring of subtidal reefs in Jervis Bay MP (Barrett *et al.* 2007).

NB: A lot of the monitoring done by the NSW MPA has been to assess the compliance of the NSW MPs with the Comprehensive Adequate & Representative (CAR) principles (e.g. Malcolm *et al.* 2007), and does not evaluate the effectiveness of the MPs. This ecological monitoring has addressed the zoning requirements of the NSW MPAs (to ensure MPAs meet the CAR principles). Additionally, although the system of NSW MPs exist there is very little co-ordinated monitoring effort at the state level, rather there are park specific research projects (e.g. for JBMP - NSW Marine Parks Authority 2011a).

The case study detailed here is a part of a national monitoring programme, which is only partially funded by NSW MPA - NSW MPA have contributed funding to an Australian Research Council (ARC) Linkage grant and provided in kind support (e.g. field assistance) to the project. From 2009, this monitoring programme was taken over by NSW Government Marine Parks Authority scientists (NSW Marine Parks Authority 2010b).

Who monitors
Tasmanian Aquaculture and Fisheries Institute (TAFI) scientists (from 2009 taken over by NSW Government Marine Parks Authority scientists; NSW Marine Parks Authority 2010b)

APPENDIX 1 - CASE STUDY 6: Ecosystem Monitoring, New South Wales Marine Parks, Australia.

Primary contacts
Dr Nathan Knott, Research Scientist, NSW Government Marine Parks Authority

Dr Alan Jordan, Senior Environmental Scientist, Waters and Coastal Science, NSW Department of Environment, Climate Change and Water

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the monitoring technical reports (Barrett *et al.* 2007). However, there is a general acknowledgement of the aims of MPAs in Australia to ensure long-term sustainability of coastal ecosystems. Also, justification for biological measures – 'the methodology focuses on reef systems as these are generally the most heavily exploited habitats and are therefore likely to show the greatest change following protection'.

Monitoring programme objectives
To determine:
- changes in population numbers and size-structure of heavily exploited species,
- cascading ecosystem effects associated with fishing,
- long term change and variability in reef assemblages across the region.

What is monitored
- Sub-tidal rocky reefs communities (fish, algae and invertebrates) at 5-10 m depth.

Scale of the monitoring program
Spatial: "No-take" and "Take" sites within Jervis Bay MP (Total area 21,000 ha, with 19% of this area closed to fishing, e.g. "no-take").

Temporal: Monitoring since 1996. Annual surveys from 2003-2007. JBMP was established in 1998, but it was not until 2002 that restrictions on fishing were introduced (Barrett *et al.* 2007). Since 2009, monitoring has been continued by NSW Government MPA scientists.

Monitoring design
Spatial replication:
- Twenty seven sites surveyed (from different 'use zones'), 18 of these were 'no-take'.
- Sampling unit: at each reef a 200m long transect (split into four 50m units) is surveyed.

Temporal replication:
- Annual surveys from 2003-2007.

<u>Data collection method:</u>
Underwater visual census (using SCUBA divers) of:
- Fish (density and estimated size-class) within 5 m of each side of the 50 m transect line (2 records taken from swimming up and back).
- Megafaunal invertebrates and cryptic fish within 1 m of one side of the transect (a total of four 1 x 50 m sections).
- The maximum shell length of abalone and the carapace length of rock lobsters were measured underwater along each transect.
- The cover of macroalgae is estimated using 0.25 m^2 quadrat (with a grid of 7x7 perpendicular wires; i.e. 50 points) at 10 m intervals along the transect line.

Statistical analysis used

<u>Assessment of temporal trends (evaluation of trends at MPA and Reference sites):</u>

- Non-metric MDS plots are used to display the community structure (algal, invertebrates and fish communities) to assess differences between Year and Management zone (see **Figure 6-1**).
- Temporal patterns in species abundance are plotted (mean ± standard error) as time-series plots (**Figure 6-2**) and bar graphs (**Figure 6-3**) and are assessed using repeated measured ANOVA (testing for differences between Year and Management zone (fixed factors)).
- The size of commonly exploited fish is plotted for Take and No Take sites over years (
- **Figure 6-4**), but no statistical analysis done.

Results to date

- Very few effects of 'no-take' zones have been detected, but as Barrett *et al.* (2007) explain, this is not surprising given that sanctuary zones in the JBMP have only been protected for 4.5 years. A more realistic and biologically meaningful timeframe to detect change will be 5-10 years, as resident species recruit to reefs and grow in size.

Reporting style

Long-term monitoring results from Jervis Bay MP have been reported in government technical reports (Barrett *et al.* 2007), and in one scientific paper (Edgar and Stuart-Smith 2009). There are no non-technical summary reports which specifically address individual MPs or groups of MPs based on long-term monitoring data.

NSW MPA conduct research which fits within five research themes to help assess various aspects of the system of NSW Marine Parks and many of these projects are led by or in collaboration with other organisations/universities (NSW Marine Parks Authority 2010a). The reporting requirements are project specific, but include the publication of government technical reports and scientific papers.

Instead of publishing technical reports, the NSW MPA focus on producing high quality peer-reviewed scientific papers (listed on their website: NSW Marine Parks Authority 2006) to ensure the scientific credibility of published work. To date, the NSW MPA have not reported on the results from monitoring from 2008 onwards.

Reporting frequency and availability of reports

The case study detailed here is reported in a technical report (Barrett *et al.* 2007), which is not publicly available or updated at regular intervals. Rather this data is primarily used in scientific papers (e.g. Edgar *et al.* 2009).

References

Barrett NS, Edgar GJ, Polacheck AS, Lynch T, Clements F (2007) Ecosystem Monitoring of Subtidal Reefs in the Jervis Bay Marine Park. A report to Jervis Bay Marine Park, Tasmanian Aquaculture and Fisheries Institute, Hobart.

Edgar GJ, Barrett NS, Stuart-Smith RD (2009) Exploited reefs protected from fishing transform over decades into conservation features otherwise absent from seascapes. Ecological Applications 19:1967-1974

Malcolm HA, Gladstone W, Lindfield S, Wraith J, Lynch TP (2007) Spatial and temporal variation in reef fish assemblages of marine parks in New South Wales, Australia - baited video observations. Marine Ecology-Progress Series 350:277-290

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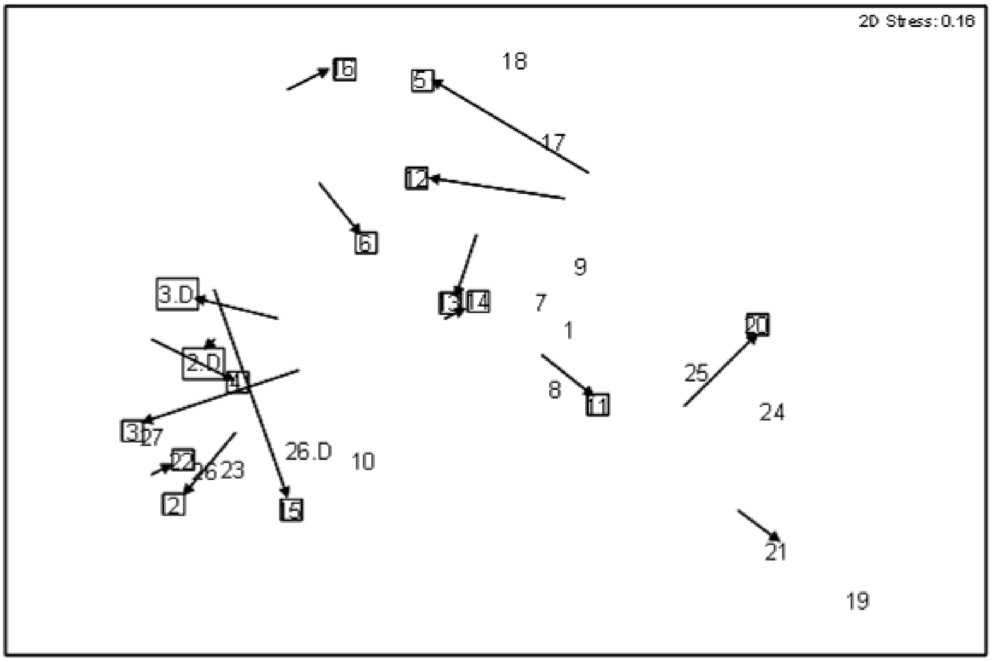

Figure 2. Two-dimensional MDS plot showing the relationship between sites based on 2007 fish assemblage data. Arrows show change from 2003 (pre-protection) to 2007 for sites located in sanctuary zones. Sanctuary site labels are placed in a square and sites surveyed at 10 m depth are shown with a "D" suffix.

Figure 6-1. MDS plot of fish assemblage structure showing change in time and space (Source: Barrett *et al.*, 2007, p. 15).

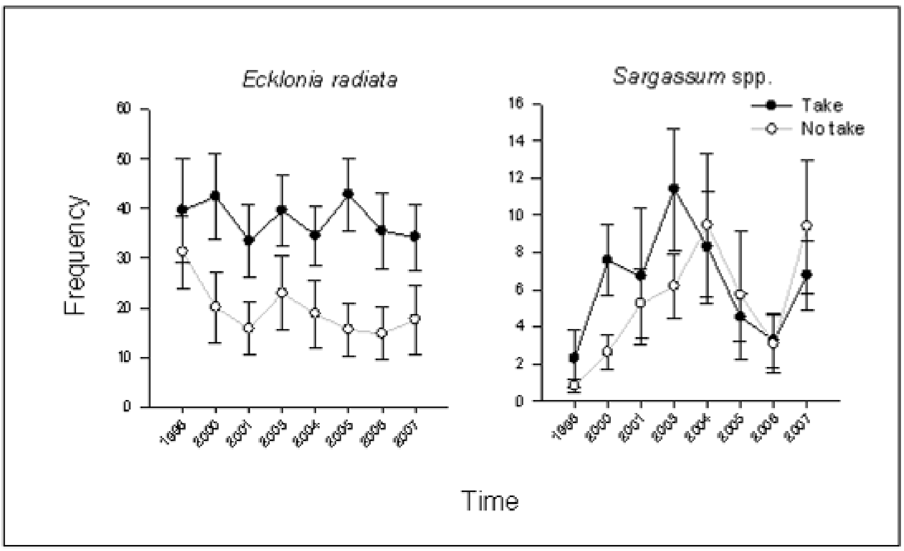

Figure 11. Inter-annual variation in the mean abundance (percentage cover) per site of common algae censused during surveys at sites 1 to 18 in 1996, 2000, 2001, 2003, 2004, 2005, 2006 and 2007 at 5m depth contour. (note sites 2 and 3 are excluded in 1996 as they were only conducted at 10m depth)

Figure 6-2. Temporal trends in algal cover between Take and No Take sites (Source: Barrett *et al.*, 2007, p. 32).

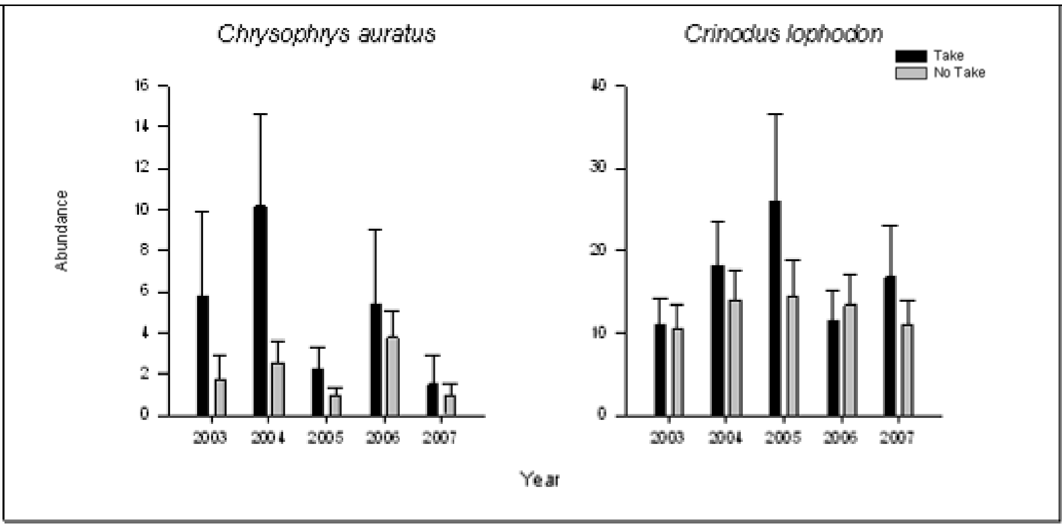

Figure 4. Between zone variation in the mean per site abundance of common fishes censused during surveys at sites 1 to 27 in 2003 to 2007.

Figure 6-3. Temporal trends in fish abundance Take and No Take sites (Source: Barrett *et al.*, 2007, p. 32).

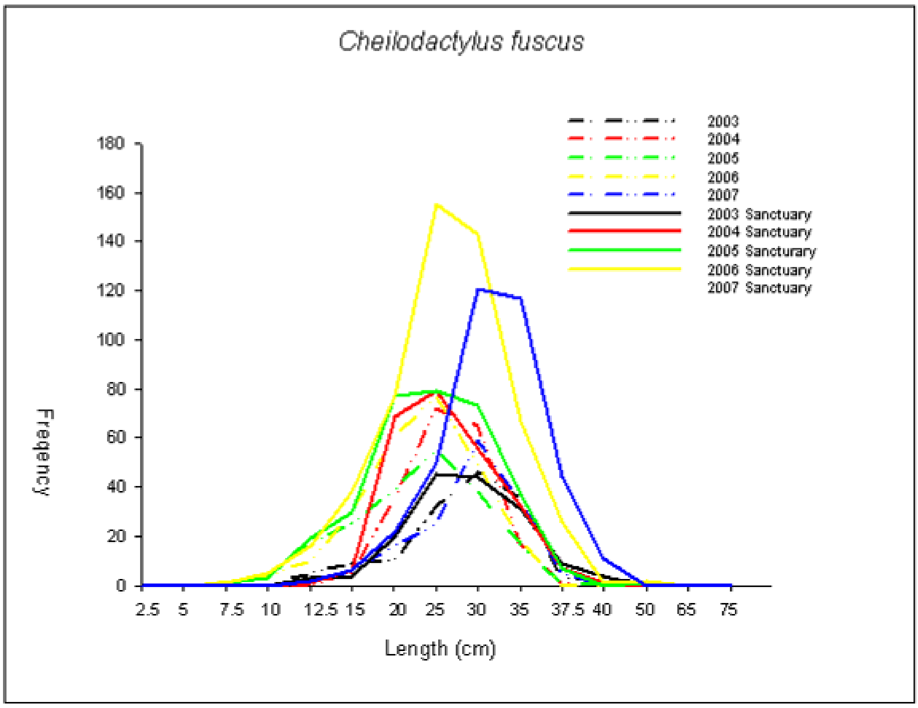

Figure 5. Size distribution of *Cheilodactylus fuscus* within the Jervis Bay MPA during surveys undertaken between 2003 and 2007.

Figure 6-4. The size of a commonly exploited fish plotted for Take and No Take sites over years (source: Barrett *et al.*, 2007, p. 24).

CASE STUDY 7: Fish Monitoring, CROP Marine Reserve, New Zealand

MPA: New Zealand Marine Reserves

Managing Agency: Department of Conservation (DoC)

Park details
A system of Marine Reserves were established in New Zealand from 1975 onwards. The Cape Rodney to Okakari Point (CROP) Marine Reserve (also known as Leigh Marine Reserve), is the oldest MPA in New Zealand which was established in 1975, and covers an area of 549.16 ha (Babcock *et al.* 1999). Of New Zealand's total marine environment, just 0.3% is protected in Marine Reserves (Department of Conservation 2011).

MPA conservation objectives
New Zealand's Marine Reserves have been established to incorporate a full set of complementary sites representing a range of marine communities (Walls 1998). They have been established 'in areas that contain underwater scenery, natural features, or marine life of such distinctive quality, or so typical, beautiful or unique that their continued preservation is in the national interest' (Department of Conservation 2011).

Biological monitoring programmes
Biological monitoring is conducted and reported on an individual reserve basis, and generally includes:
- Fish populations (over a variety of habitats)
- Reef invertebrates and algae
- Lobster populations

Monitoring Programme Case Study
CROP Marine Reserve fish monitoring (Haggitt *et al.* 2008).

Who monitors
Coastal & Aquatic Systems Limited (consultants employed by DoC).

Primary contact
Dr Tim Haggitt, Coastal and Aquatic Systems Ltd

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the monitoring technical reports (Haggitt *et al.* 2008).

Monitoring programme objectives
- To determine whether populations have recovered within reserves relative to fished areas.
- To assess the natural variability associated with species abundance in particular locations.
- To assist in the interpretation of environmental and habitat changes arising indirectly from changes in the relative density of predators (trophic cascades).

What is monitored
Fish communities over a variety of habitats.

Scale of the monitoring program
Spatial: CROP Marine Reserve (549.16 ha; Babcock *et al.* 1999) and associated control sites.

Temporal: Every 1-3 years, since 2000. This monitoring is a continuation of the scientific surveys of CROP Marine Reserve which began in 1978 (e.g. Babcock *et al.* 1999).

Monitoring design
Spatial replication:
- Multiple sites (Random, but re-visited each year) within and outside of CROP Marine Reserve.
- Sampling units: within each site ten haphazardly placed 25 m x 5 m transects are surveyed by divers.

Temporal replication:
- Autumn and Spring monitoring from 2000-2002, and subsequently in 1-3 yr intervals (2003, 2005, 2008).

Data collection method:
- A visual census of fish species is made along the transect.
- Depth and % cover of broad habitat types (following Shears *et al.* 2004) was also noted.
- Usually monitoring also involves Baited Underwater Video (BUV) to estimate some fish species, however this was not done in 2008 due to funding issues (T. Haggitt pers comm.).

Statistical analysis used
<u>Assessment of temporal trends (evaluation of trends at MPA and Reference sites):</u>
- The abundance of commercially important fish species were plotted through time (mean ± s.e.; see **Figure 7-1**). No statistical analysis done on these plots.

<u>Assessment of spatial differences:</u>
Multivariate analyses:
- Bray-Curtis dissimilarities (data ln(y +1) transformed) used for all multivariate analyses.
- Principal Coordinate Analysis - to visualise the relative dissimilarities in the fish assemblages between different stations.
- Permutational multivariate analysis of variance (PERMANOVA) - to analyse whole assemblages, with “Status” (reserve versus non-reserve) treated as a fixed factor and “Areas” treated as a random factor, nested within “Status”.
- Canonical analysis of principal coordinates (CAP) analysis - to determine the species responsible for the differences in assemblage patterns.

Univariate analyses:
- Univariate, two-way nested ANOVA (for total number of species and the total number of individuals) - to investigate differences between ‘Status’ (reserve versus non-reserve; Fixed factor) and “Areas” (Random factor). Bar plots were used to support ANOVA (**Figure 7-2**).
- The size of commercially important species were plotted and compared with paired Wilcoxon signed rank test.

Results to date
- Single year analyses (e.g. all the multivariate analyses and ANOVA) showed some significant effects on the abundance of some species (higher in CROP Marine Reserve – snapper and blue cod).
- Temporal data showed substantial variability in fish abundance through time and a general decline in some fish species within the Marine Reserve, but authors highlight that this may be due to migration for spawning.

- Reef fish assemblage within CROP Marine Reserve is significantly distinct from that found in adjacent fished areas (which may, in part, be related to habitat differences between the areas surveyed).

Reporting style
Long-term monitoring data is presented in government technical reports (e.g. Haggitt *et al.* 2008). Scientific papers also summarise long-term results (e.g. Shears & Babcock 2003). Data from this monitoring programme has contributed to a recent review (Babcock *et al.* 2010). There are no non-technical summary reports (Report Card / Status Reports) produced by DoC evaluating the effectiveness of New Zealand's system of Marine Reserves.

Reporting frequency and availability of reports
Government technical reports have been produced following each year of monitoring and are available on the Department of Conservation website.

References

Babcock RC, Kelly S, Shears NT, Walker JW, Willis TJ (1999) Changes in community structure in temperate marine reserves. Marine Ecology-Progress Series 189:125-134

Babcock RC, Shears NT, Alcala AC, Barrett NS, Edgar GJ, Lafferty KD, McClanahan TR, Russ GR (2010) Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects. Proceedings of the National Academy of Sciences of the United States of America 107:18256-18261

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Shears NT, Babcock RC, Duffy CAJ, Walker JW (2004) Validation of qualitative habitat descriptors commonly used to classify subtidal reef assemblages in north-eastern New Zealand. New Zealand Journal of Marine and Freshwater Research 38:743-752

Walls K (1998) Leigh Marine Reserve, New Zealand. Parks 8:5-10

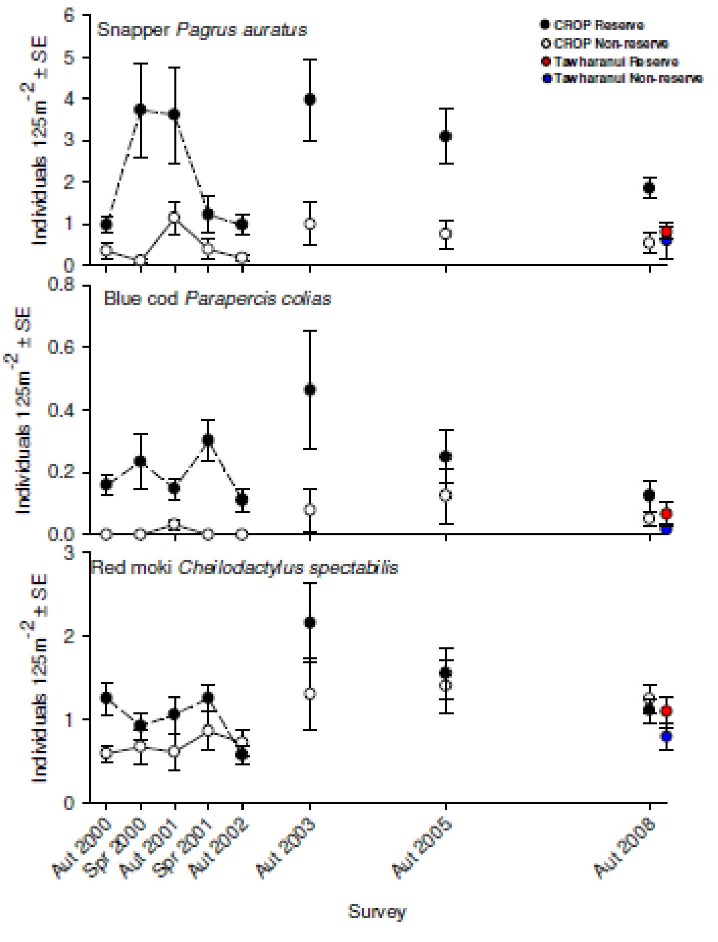

Figure 3.6. Long term trends in the densities of snapper, blue cod, and red moki inside and outside the Cape Rodney to Okakari Point Marine Reserve, as measured using UVC between 2000 and 2008 and inside and outside Tawharanui Marine Park in 2008. Note: y axis scale differs among plots.

Figure 7-1. Example of long-term trends plotted for key fish species (Source: Haggitt et al, 2008, p. 17).

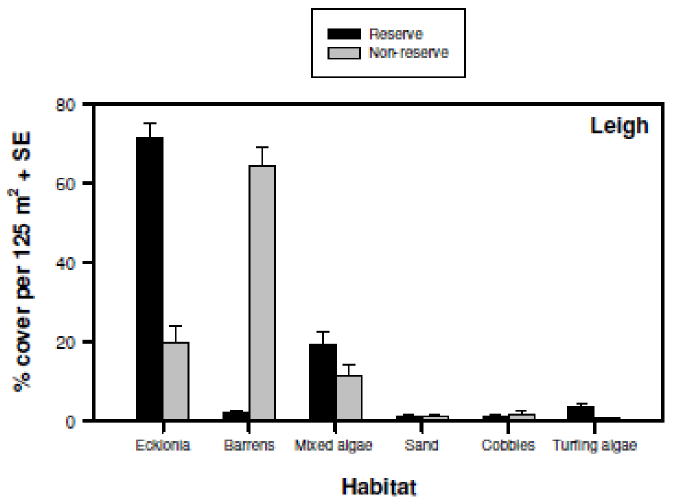

Figure 3.3. Main habitat types (pooled across areas) for Leigh and Tawharanui reserve and non-reserve locations surveyed in 2008.

Figure 7-2. Bar graph showing spatial differences of habitats between MR and Reserve sites (Source: Haggitt et al, 2008, p. 10).

CASE STUDY 8: Fish Monitoring, Channel Islands National Marine Sanctuary, U.S.A.

MPA: Channel Islands Marine Protected Areas network, California, U.S.A.

Managing Agency: California Department for Fish and Game (CDFG)

Park details
The Channel Islands Marine Protected Areas (MPA) network was established in 2003 and encompasses 82,400 ha, making it at the time, the largest MPA network off of the continental United States (California Department of Fish and Game 2011, National Oceanic and Atmospheric Administration 2011). Within the Channel Islands MPA network there are 11 "no-take" State Marine Reserves, and two State Marine Conservation Areas that allow limited take of some commercially important species (National Oceanic and Atmospheric Administration 2011). The oldest State Marine Reserve which is now part of the Channel Islands MPA network is the Anacapa Island Marine Reserve, which was established by the state of California (managing agency: National Park Service) in 1978 (Protect Planet Ocean 2010).

In 2006 to 2007, National Oceanic and Atmospheric Administration (NOAA) created the Channel Islands National Marine Sanctuary (NMS) as an extension of the state Channel Islands MPA network to cover waters from 3 to 6 nautical miles off shore from the existing state MPA network boundary of 3 nm (National Oceanic and Atmospheric Administration 2011). The Channel Islands NMS has 17 regulatory bodies, the military and one non-profit organization involved in its complex jurisdiction and management (Office of National Marine Sanctuaries 2009).

The focus of this case study is the Channel Islands MPA network (from high tide to 3 nm), where the majority of active management and monitoring occurs (D. Kushner pers comm.).

MPA biological conservation objectives
The Channel Islands MPA network is designed to:
- Protect the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems.
- Sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted.

(From California Department of Fish and Game 2004)

Biological monitoring programmes
Monitoring within the state Channel Islands MPA network (not the Channel Islands NMS which is 3-6 nm offshore) is described as a 'cooperative effort' among established university and agency field research programs, as well as volunteer and contracted data collection efforts (California Department of Fish and Game 2004). There are four general habitat/ecosystem categories for which monitoring is conducted (California Department of Fish and Game 2004):
- Shallow subtidal reefs (algae, invertebrates and fish)[2]
- Deep subtidal reefs (fish and invertebrates)
- Intertidal reefs (algae and invertebrates)
- Seabirds and marine mammals

[2] Shallow subtidal reef monitoring is the highest priority monitoring activity within Channel Islands MPA network (California Department of Fish and Game 2004). This monitoring is done through the Kelp Forest Monitoring programme conducted by the National Park Service (NPS) and subtidal reef monitoring done by Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO).

APPENDIX 1 - CASE STUDY 8, Fish Monitoring, Channel Islands National Marine Sanctuary, U.S.A.

The longest running monitoring which has occurred within the Channel Islands MPA network is the NPS Kelp Forest Monitoring program which began in 1982 (U.S. National Park Service 2010a,b). This program collects population data on over 70 species of algae, invertebrates, and fish (U.S. National Park Service 1997, 2010). To date complete analysis of the entire dataset has never been undertaken (Kushner pers comm.). Only subsets of the data have been analysed, for example fish, invertebrate and algae data from Anacapa Island State Marine Reserve from 1982 – 2008 which was used to contribute to a recent paper on decadal trends of MPAs (Babcock *et al.* 2010).

Monitoring Programme Case Study
PISCO fish monitoring programme (Hamilton *et al.* 2010).

This was chosen as a case study, as it appears to be the most recent publication of long-term monitoring data which has also been used to assess the condition of the Channel Islands MPA network (California Department of Fish and Game 2008) and the Channel Islands NMS (Office of National Marine Sanctuaries 2009).

Who monitors
Scientists from PISCO and NPS

Primary contact(s)
David Kushner, Marine Biologist, Channel Islands National Park, National Park Service Kelp Monitoring Program

Dr Jenn Caselle, PISCO, University of California Santa Barbara

Acknowledgement of MPA conservation objectives?
This paper does not explicitly state the conservation objectives of the Channel Islands MPA network. Instead, this paper aims to provide guidance for evaluating MPA network performance in light of biogeographic effects.

Monitoring programme objectives
- To identify geographic patterns of community structure (i.e. bioregions) and to define appropriate scales over which to group sites for reserve performance evaluations.
- To assess the density and biomass response of common fish species (based on target status or trophic group) inside and outside of reserves.
- Hypothesis tested: That targeted (i.e. fished) species will show a positive response across the reserve network compared to non-targeted species and that higher trophic level predators (e.g. piscovores and carnivores) will show a stronger response to protection because these species are commonly fished.

What is monitored
Fish and habitat information for nearshore kelp beds and rocky reefs.

Scale of the monitoring program
Spatial: Surveys of multiple sites (no number provided, but appears to be at least 50 sites) within and outside of the numerous Marine Reserves in the Channel Island MPA network (48,800 ha).

Temporal: Hamilton *et al.* 2010 present data from annual surveys from 1999-2008 (Channel Islands MPA network established in 2003), monitoring is ongoing.

APPENDIX 1 - CASE STUDY 8, Fish Monitoring, Channel Islands National Marine Sanctuary, U.S.A.

Monitoring design
Spatial replication:

- Multiple reef sites within and outside of the numerous Marine Reserves in the Channel Island MPA network.
- Transects are randomly stratified into fixed outer, middle, and inner edges of the reef (stratified random design).
- Sampling units: 8-12 transects (5-20 m deep) are surveyed within each reef at multiple levels in the water column: benthic, midwater, and canopy.

Temporal replication:

- Surveys at least annual since 1999.

Data collection method:

- Underwater visual census of fish along transects (30 x 2 x 2 m) where one diver counts and sizes all fish to the nearest centimeter (total length), excluding small cryptic fishes (e.g. gobies).

Statistical analysis used

- A number of analyses were used solely to assess the influence of biogeographic patterns on assemblages, prior to evaluation of the MPA network. These will not be discussed here. The following statistical analyses were used to evaluate the effectiveness of the MPAs:

<u>Assessment of spatial differences (comparison of Marine Reserves vs Reference Site)</u>

- Non-metric multidimensional scaling (MDS) analysis of the 30 most common fish species across sites.
- The Average Response Ratio (ARR) was calculated for targeted and non-targeted fish species. This was based on the average response (density or biomass) of particular species to sites inside reserves vs sites outside reserves on each island in a given year. The average ± s.e. is presented for the years 2005-2008. These values were log transformed and presented in graphical format (see **Figure 8-1**).
- One way ANOVA used to assess the effect of Reserve on the density and biomass of species targeted and non-targeted fish species (averaged across all years) (see bar graphs in **Figure 8-2**).
- Two way ANOVA (two fixed factors: Island and Reserve) used to assess the effect of bioregions (Island) (see bar graphs in **Figure 8-2**).
- Two factor ANOVA (fixed factors: Island and Reserve) used to assess the biomass of different trophic levels (see **Figure 8-3**).

<u>Assessment of temporal trends (evaluation of trends at Marine Reserves and Reference sites):</u>
Temporal trends in biomass (see scatter plots in **Figure 8-2** and ARR of targeted and non-targeted species (see **Figure 8-3**) across the reserve and non reserve sites were assessed using ANCOVA (with the factors of reserve, year, and reserve × year).

Results to date

- This case study by Hamilton *et al.* 2010 revealed significant effects of reserves on targeted fish biomass and abundance after 5 years of monitoring, but no significant effects on non-targeted fish species (as was hypothesised). The authors noted that the lack of significant reserve x time interactions for targeted species biomass is likely to be because of high site-level variance in biomass, which may be attributed in part to annual monitoring and associated sampling error (e.g., variation in visibility, current, and swell). Given sampling constraints, this result suggests a trade-off between spatial coverage and sampling frequency that may affect the time required to conclusively attribute observed differences in biological responses to a reserve effect.

There is a non-technical summary report for managers and the non-scientific community which presents the results from the first five years of monitoring of the Channel Islands MPA network (California Department of Fish and Game 2008). This presents the scientific results contained within Hamilton *et al.* (2010) in a simplified fashion (see **Figure 8-5**) and graphical presentation of unpublished data from other organisations (i.e. data providers are mentioned, but no specific references given to existing reports/papers). These results are then fed into an even higher Condition Report (Office of National Marine Sanctuaries 2009) where the condition of biological elements within 'Living Resources' are assessed (see **Table 8-1**). The authors of the Condition Report stated that they relied heavily on the expertise and best professional judgment of local researchers and authorities (Office of National Marine Sanctuaries 2009), and according to the NPS many of the assessments made were predominantly based on questionnaires sent to organizations involved in monitoring on Channel Islands NMS (D. Kushner pers comm.).

NB. This case study revealed the only example of predicted Effect Sizes noted in the Channel Islands MPA network monitoring plan (California Department of Fish and Game 2004; see **Table 8-2**). These predicted effect sizes however have not been acknowledged in any monitoring results (e.g. Hamilton *et al.* 2010) or the Channel Islands MPA network summary of the first five years of monitoring (California Department of Fish and Game 2008, Office of National Marine Sanctuaries 2009).

Reporting style

There are no publicly available government technical/status reports which detail the analysis of monitoring data, however there are scientific papers (e.g. Hamilton *et al.* 2010) and non-technical summary reports (e.g. California Department of Fish and Game 2008, Office of National Marine Sanctuaries 2009). Also, data from the longest running KFM monitoring programme has contributed to a recent review (Babcock *et al.* 2010).

Reporting frequency and availability of reports

The non-technical summary reports (which aim to be produced every five years) are available on the CDFG website and the NOAA NMS website.

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APPENDIX 1 - CASE STUDY 8, Fish Monitoring, Channel Islands National Marine Sanctuary, U.S.A.

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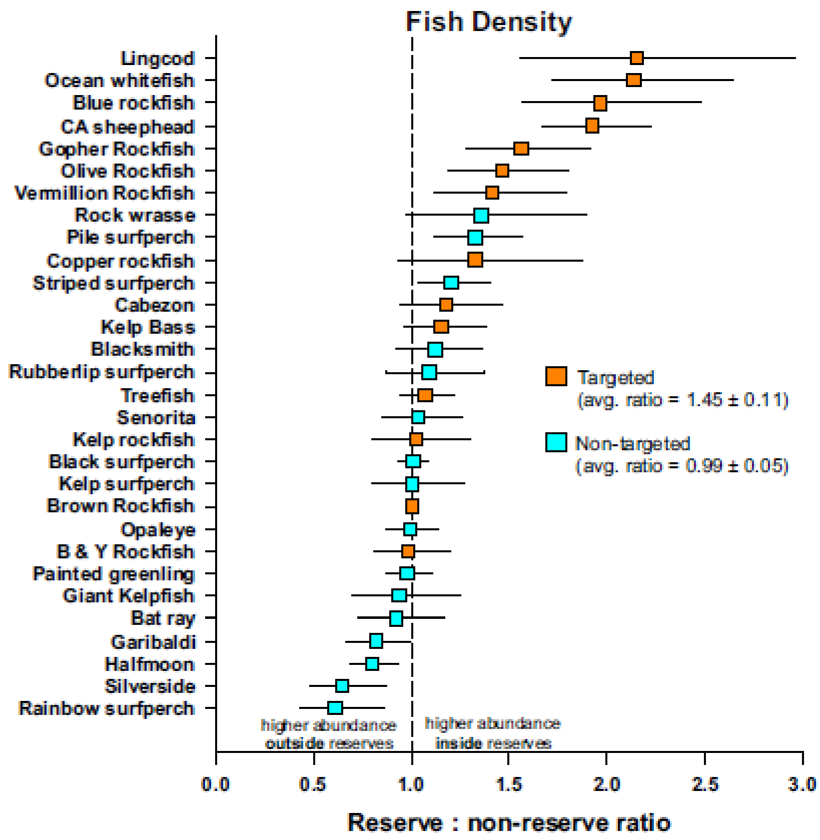

Fig. 4. ARRs (density inside/density outside) for individual targeted and nontargeted species of fish in the Channel Islands reserve network. Values represent the back-transformed average of the log response ratios for each island. Error bars are ± SE.

Figure 8-1. Average Response Ratio (ARR) targeted and non-targeted fish species to demonstrate the Reserve: non-reserve ratio (Source: Hamilton *et al.*, 2010, p. 3).

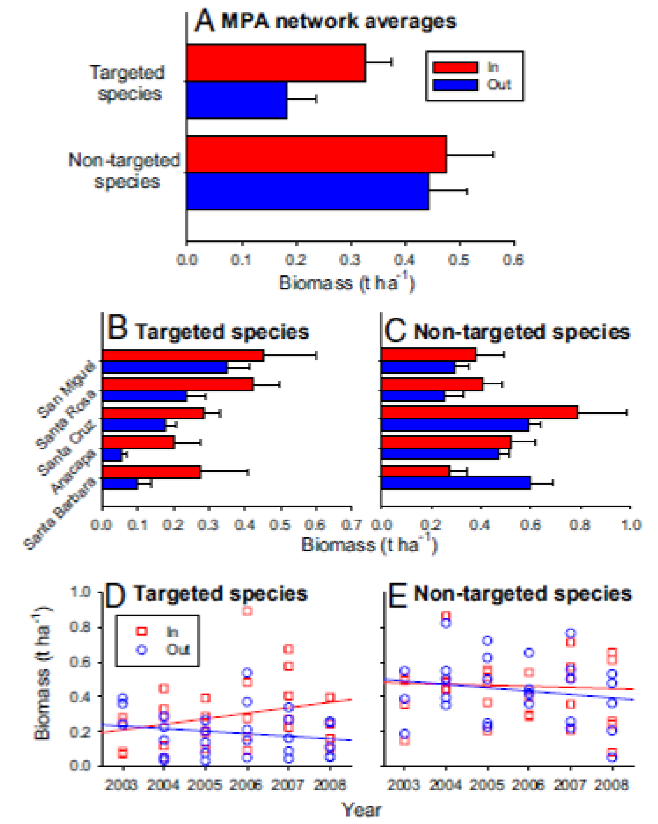

Fig. 5. Spatial and temporal patterns of biomass for targeted and non-targeted species inside (red bars or squares) and outside (blue bars or circles) of reserves in the Channel Islands. (*A*) Averages across all islands in the reserve network, (*B*) targeted species biomass for each island, (*C*) non-targeted species biomass for each island, (*D*) time series of targeted species biomass, and (*E*) time series of nontargeted species biomass. Biomass is reported in metric tons per hectare. Error bars are ± SE.

Figure 8-2. Bar graphs (A – C) used to support ANOVA results, and time series (D-E) to support ANCOVA results (Source: Hamilton *et al.*, 2010, p.3).

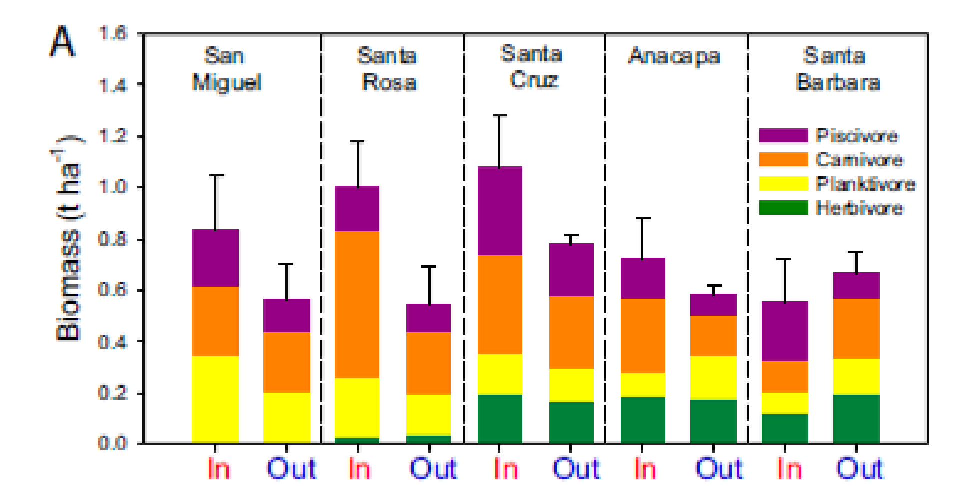

Fig. 6. (*A*) Biomass of different trophic groups of fishes at sites inside and outside of reserves on each island in the Channel Islands reserve network. (*B*) ARRs (biomass inside/biomass outside) for each trophic group across the Channel Islands reserve network. Response ratios are the back-transformed average of the log response ratios. Error bars are ± SE.

Figure 8-3 The biomass of different trophic levels inside and outside reserves on different islands used to support ANOVA results (Source: Hamilton *et al.*, 2010, p. 4).

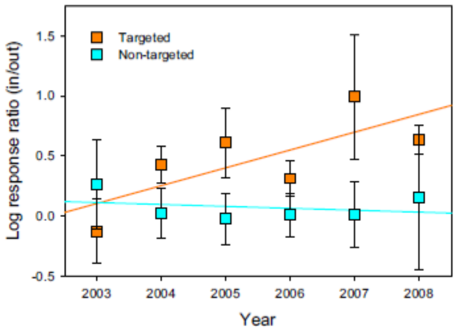

Fig. S3. Time series of log response ratios (biomass inside/biomass outside) for targeted and nontargeted fish species in the Channel Islands reserve network. Values represent the ARR using islands as replicates across the different years surveyed since the marine reserves were enacted in 2003. Positive values indicate greater biomass inside reserves and negative values indicate greater biomass outside reserves. The biomass of targeted species increased inside reserves relative to outside, whereas the biomass of nontargeted species showed no change inside or outside of reserves (by ANCOVA, target status $F_{1,8}$ = 10.52, P = 0.012; year $F_{1,8}$ = 3.30, P = 0.11; target status × year, $F_{1,8}$ = 5.07, P = 0.054). Error bars represent ± SE.

Figure 8-4. Temporal trends of ARR for targeted and non-targeted fish (Source: Hamilton *et al.*, 2010, Supporting Information, p. 2).

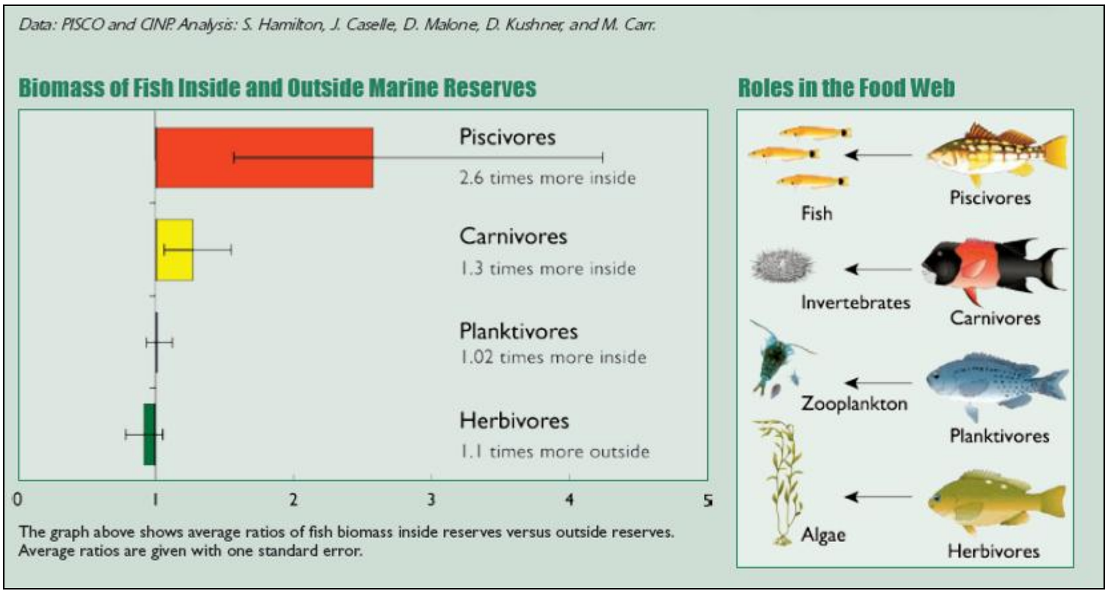

Figure 8-5. Simplified data presentation for the Channel Islands NMS five year monitoring results summary (Source: California Department of Fish and Game, 2008, p. 11)

APPENDIX 1 - CASE STUDY 8, Fish Monitoring, Channel Islands National Marine Sanctuary, U.S.A.

Table 8-1 Channel Island NMS Condition Report - Assessment of biological components (living resources) (Source: Office of National Marine Sanctuaries, 2009, p.5)

Channel Islands National Marine Sanctuary Condition Summary Table (Continued)

#	Questions/Resources	Rating	Basis for Judgment	Description of Findings	Sanctuary Response
LIVING RESOURCES					
9	What is the status of biodiversity and how is it changing?	?	Extraction of fish (e.g., sheephead, kelp bass, rockfish) and invertebrate (e.g., lobster and abalone) species has decreased biodiversity and simplified community structures (e.g., dominance of urchins and brittlestars).	Selected biodiversity loss may inhibit full community development and function, and may cause measurable but not severe degradation of ecosystem integrity.	Marine reserves and other regulations have recently been established which are expected to help some species recover over time. Early indications are that reserves will increase biomass, species numbers, and will allow parts of system to recover to a more resilient state. Monitoring programs record presence of non-indigenous species if they are observed.
10	What is the status of environmentally sustainable fishing and how is it changing?	▲	Declines have occurred in several species of sharks, giant sea bass, swordfish, various rockfish, and abalone populations; recent implementation of marine reserves may improve conditions.	Extraction has caused or is likely to cause severe declines in some but not all ecosystem components and reduce ecosystem integrity.	
11	What is the status of non-indigenous species and how is it changing?	▼	No problematic species have become established; there is concern that invasive algae from mainland harbors and Santa Catalina Island could reach the islands.	Non-indigenous species are not suspected or do not appear to affect ecosystem integrity (full community development and function).	
12	What is the status of key species and how is it changing?	—	Removal of key species, including sea otters, led to an increase in urchins and urchin barrens. Some species (black sea bass and lobsters) have shown recent increases, but do not approach historic levels.	The reduced abundance of selected keystone species may inhibit full community development and function, and may cause measurable but not severe degradation of ecosystem integrity; or selected key species are at reduced levels, but recovery is possible.	
13	What is the condition or health of key species and how is it changing?	?	Withering foot syndrome in abalone, small size of fished species, low fecundity in sea birds; although some birds have shown recent recovery from reproductive impairment from high levels of DDT.	The diminished condition of selected key resources may cause a measurable but not severe reduction in ecological function, but recovery is possible.	
14	What are the levels of human activities that may influence living resource quality and how are they changing?	▼	Increased visitation and potential disturbance along with expected climate change offset gains made in resource protection.	Selected activities have resulted in measurable living resource impacts, but evidence suggests effects are localized, not widespread.	

Status: Good | Good/Fair | Fair | Fair/Poor | Poor | Undet.

Trends:
Conditions appear to be improving .... ▲
Conditions do not appear to be changing .... –
Conditions appear to be declining .... ▼
Undetermined trend. .... ?
Question not applicable .... N/A

Table 8-2 Table of predicted effect sizes on key species from the Kelp Forest Monitoring program (Source: California Department of Fish and Game, 2004, p.15)

Table 4. Ranges of estimated potential differences in focal species density and size within reserves compared to areas outside based on data from other California MPAs.

Species	Estimated Density Difference (%)	Estimated Size Difference (%)
California sheephead	50 to150	15
Cabezon	20	No Data
Kelp bass	30 to 100	10
Lingcod	100	No Data
Kelp rockfish	30	15
Gopher rockfish	80	15
Garibaldi	-40 to 80	-5
Rock wrasse	-40 to 175	5
Black Surfperch	400	-25
Red sea urchin	-15	60
Sea cucumbers	140	No Data
Lobster	600	No Data
Sea stars	-60 to -80	No Data
Purple urchin	-90	No Data

CASE STUDY 9: Coral Reef Evaluation and Monitoring Project, Florida Keys National Marine Sanctuary, U.S.A.

MPA: Florida Keys National Marine Sanctuary (NMS), Florida, U.S.A.

Managing Agency: National Oceanic and Atmospheric Administration, National Marine Sanctuaries (NOAA NMS) and the National Park Service (NPS)

Park details
The Florida Keys NMS was designated in 1990 and covers an area of 984,400 ha (Keller & Donahue 2006). The coral reef tract within Florida Keys NMS is one of the largest bank-barrier reef systems in the world and Florida Keys NMS also contains one of the largest seagrass communities in the northern hemisphere (National Oceanic and Atmospheric Administration 2007). In 2001 the Florida Keys NMS included the addition of the relatively undisturbed and unique coral reef ecosystem, Tortugas Ecological Reserve, which has been the focus of a substantial amount of scientific study (National Oceanic and Atmospheric Administration 2007).

MPA conservation objectives
The Florida Keys NMS was designated to protect and conserve nationally significant biological and cultural marine resources of the area, including critical coral reef habitats, seagrass beds, hard-bottom communities, and mangrove shorelines (National Oceanic and Atmospheric Administration 2007).

Biological monitoring programmes

- Coral reef and other hard-bottom communities (invertebrates, algae and fish) monitoring conducted under various projects (Keller & Donahue 2006).
- Seagrass (associated with water quality monitoring)

Monitoring Programme Case Study
Coral Reef Evaluation and Monitoring Project (CREMP) – one of the one of the longest tenured monitoring programs in the State of Florida (Ruzicka *et al.* 2010).

Who monitors
Fish and Wildlife Research Institute scientists

Primary contact
Scott Donahue, Associate Science Coordinator, Florida Keys National Marine Sanctuary

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the monitoring technical reports (Ruzicka *et al.* 2010).

Monitoring programme objectives
The aim of the CREMP is to monitor the status and trends of selected coral reefs, patch reefs, and hard bottom areas in the Florida Keys NMS.

What is monitored
Coral reef communities (major benthic taxa: stony corals, octocorals, sponges, and macroalgae).

APPENDIX 1 - CASE STUDY 9: Coral Reef Evaluation and Monitoring Project, Florida Keys National Marine Sanctuary, U.S.A.

Scale of the monitoring program

Spatial: 37 fixed sites are monitored throughout the Florida Keys NMS (984,400 ha)

Temporal: Annual surveys since 1996 (Florida Keys NMS established in 1990)

Monitoring design

Spatial replication:

- 37 randomly selected reef sites (chosen through a stratified random sampling procedure (out of 40 reefs)) within the Florida Keys NMS, stratified into four habitat types: backcountry patch reef, patch reef, shallow reef, and deep reef.
- Sampling units: 2-4 fixed stations (22 m long x 2 m wide) within each reef site. A total of 109 reefs have been monitored since 1996.

Temporal replication:

- Annual surveys since 1996 (Florida Keys NMS established in 1990)

Data collection method:

Benthic community surveys:

- 20 minute inventories of a station by two divers involves the census of all stony corals, presence/absence of coral disease or bleaching, and counts of *Diadema antillarum* within a station.
- Underwater videography of transect benthos (filmed 40 cm above the reef surface). In the lab, each filmed transect is separated into about 9,000 frames and an image processing program is used to rejoin images to create a mosaic of the transect. Fifteen random points are placed over the transect and observers identify benthic taxa (e.g. stony coral to species, octocoral, zoanthid, sponge, seagrass and macroalgae) and substrate.
- The spatial coverage of clionaid sponges is assessed to evaluate sponge bio-eroding. Sponge area is estimated over a one metre wide central section of each station transect. Area is estimated with 40 cm x 40 cm quadrat divided into 25 cm^2 (5 cm x 5 cm).

Statistical analysis used

<u>Assessment of temporal trends (form of trend):</u>

- ANOVA (region and habitat groupings as fixed, and sites as random - Kenward-Roger mixed model ANOVA) was used to assess differences in benthic cover between 2007 and 2008 (macroalgae, octocorals, sponges, and stony corals) – point count data was pooled for individual stations.

Repeated measures ANOVA (region and habitat groupings over time) to determine if mean differences in species richness were significantly different across all years in the Florida Keys (N=97 stations) and Dry Tortugas. Followed by Post-hoc Tukey tests to identify significant differences between years (see **Figure 9-1**).

- Generalized mixed model regression was used to assess long-term trends in species richness (at habitat and regional level), benthic cover variables, sentinel stony coral species and clionaid sponge area. These results were plotted as time-series and trends were summarised in a Table (see a) **Figure 9-2** Time-series plot (Source: Ruzicka et al., 2010, p.27) b)**Table 9-1** Table to support the mixed model regression of cover of benthic groups through time (Source: Ruzicka et al., 2010, p.27)). Measures (Bonferroni corrections) were taken by the authors to reduce the possibility of Type I errors due to repeating the same test on multiple region*habitat groupings or sites.

<u>Assessment of spatial differences:</u>

- Graphical representation of the loss or presence of coral species from stations (shown as the number of stations) (see **Figure 9-3**). *Time not considered.
- Graphical representation of the number of colonies or statoliths affected by disease (summarised over 2007 and 2008). *Time not considered.

NB: The 02/03 five year Report Card (Keller & Donahue 2006) discusses the statistical analysis done by independent consultants on the CREMP data. This discusses the considerations to Type I and II error rates: "The decision to reject or not to reject the null hypothesis that there was no significant difference in the data for certain years, was based on the minimum detectable difference for different significance levels and powers. Combinations for significance level (α) and power (1- β) were considered: $\alpha = 0.05$, $1-\beta = 0.75$; $\alpha = 0.10$, $1-\beta = 0.75$. When the one-sided alternative was tested, the above values for α must be divided by two. The output consisted of the minimum detectable difference for a certain pair (α, $1-\beta$), which was used to construct a $(1-\alpha)$ % confidence interval and provided a measure of the test accuracy". This approach is however not mentioned in reference to the most recent monitoring results by Ruzicka *et al.* (2010).

Results to date

A number of significant declines have been detected for stony corals, sponges and species diversity as well as some significant increases in octocorals. There have also been a number of other benthic categories (e.g. macroalgae) which have shown no direction change through time. These trends are usually region and habitat specific, however Ruzicka *et al.* (2010) indicate that Florida Keys are likely to have entered into a new alternate state where octocorals are replacing stony corals as the dominant taxa.

A non-technical summary report (2002-03 Sanctuary Science Report, An Ecosystem Report Card After Five Years of Marine Zoning) for the Florida Keys NMS presents the results from the first five years of monitoring (Keller & Donahue 2006). This presents the scientific results of the CREMP in a simplified fashion such as maps showing trends in benthic groups (see **Figure 9-4**). A newer 'Condition Report' for the Florida Keys NMS is due to be published by NOAA later in 2011 (S. Donahue pers comm.).

There have been even higher level descriptions (mainly text) of the monitoring conducted within the Florida Keys NMS in USA level reports (e.g. Wusinich-Mendez & Trappe 2007, Donahue *et al.* 2008).

Reporting style

Technical/status reports (e.g. Ruzicka *et al.* 2010), scientific papers (e.g. Maliao *et al.* 2008, Schutte *et al.* 2010), and non-technical summary reports for the Florida Keys NMS (e.g. Keller & Donahue 2006). The results of this monitoring programme have also been presented in reviews (e.g. Wusinich-Mendez & Trappe 2007, Donahue *et al.* 2008).

Reporting frequency and availability of reports

Annual CREMP reports available on the Fish and Wildlife Research Institute website. Three year summaries of the CREMP results are also provided to the NOAA State of Coral Reef Ecosystems Report (Donahue *et al.* 2008). Non-technical summary reports (e.g. Keller & Donahue 2006) are due every five years, but one has not been published since 2006 (presenting monitoring results up to 2003). Scientific papers are also produced on an irregular basis.

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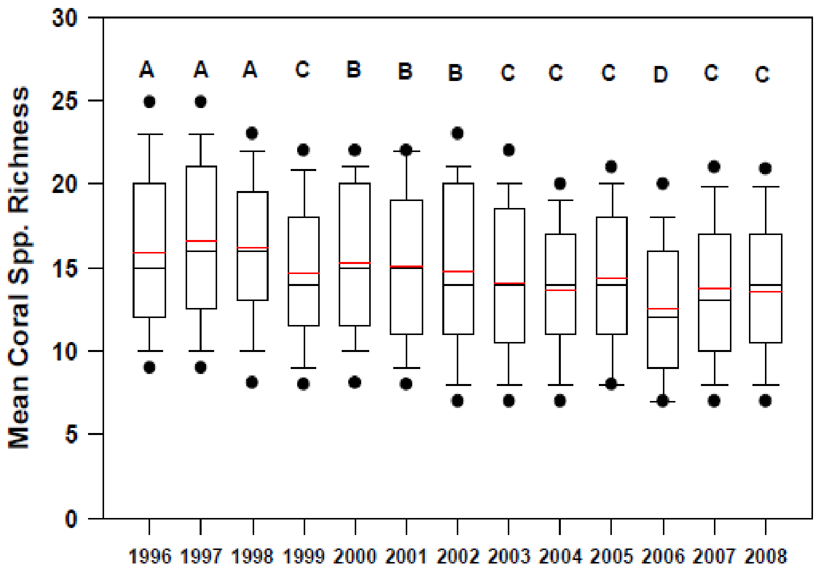

Figure 5. Boxplot of annual mean species richness in the Florida Keys ($N = 97$). Lower point, error bar and bound of the box show the 5th, 10th, and 25th percentiles of the data respectively. The solid black bar within each box represents the median. The solid red bar within each box is the mean. Upper bound of the box, error bar and upper point show the 75th, 90th, and 95th percentiles of the data, respectively. Letters above each box indicate summarized results of Tukey-Kramer pairwise comparisons. Letters denote significant differences in mean species richness across year(s) with group A>B>C>D.

Figure 9-1. Box-plots to support the Repeated Measures ANOVA and Tukey-Kramer pairwise comparisons of species richness through time (Source: Ruzicka *et al.*, 2010, p. 19).

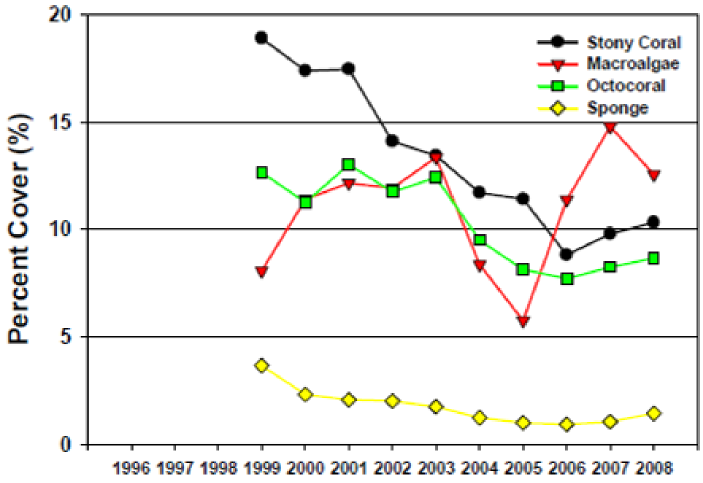

Figure 13. Mean annual percent cover for the four major benthic taxa recorded in CREMP image analysis. Mean percent cover is pooled from 12 stations in the Dry Tortugas. A mixed model regression indicates a decreasing trend for stony corals, octocorals, and sponges ($p<0.001$) and no trend for macroalgae ($p>0.05$).

a) Figure 9-2 Time-series plot (Source: Ruzicka et al., 2010, p.27**)**

b)**Table 9-1** Table to support the mixed model regression of cover of benthic groups through time (Source: Ruzicka et al., 2010, p.27)

Table 2. Long-term trends of the four major benthic taxa recorded in CREMP image analysis. Trends were determined for 10 region*habitat groupings from a mixed model regression between 1996 and 2008. Interpretation of trends for each region*habitat grouping are based on Bonferroni corrected p values for repeated testing (adjusted $p \leq 0.004$).

Reg*Hab	Stony Corals	Macroalgae	Octocorals	Sponges
LK BCP	decreasing	increasing	no change	no change
LK OD	decreasing	decreasing	no change	no change
LK OS	decreasing	no change	increasing	decreasing
LK P	decreasing	no change	increasing	no change
MK OD	decreasing	no change	no change	no change
MK OS	decreasing	no change	increasing	decreasing
MK P	no change	no change	no change	decreasing
UK OD	decreasing	no change	increasing	no change
UK OS	decreasing	no change	increasing	decreasing
UK P	decreasing	no change	no change	no change

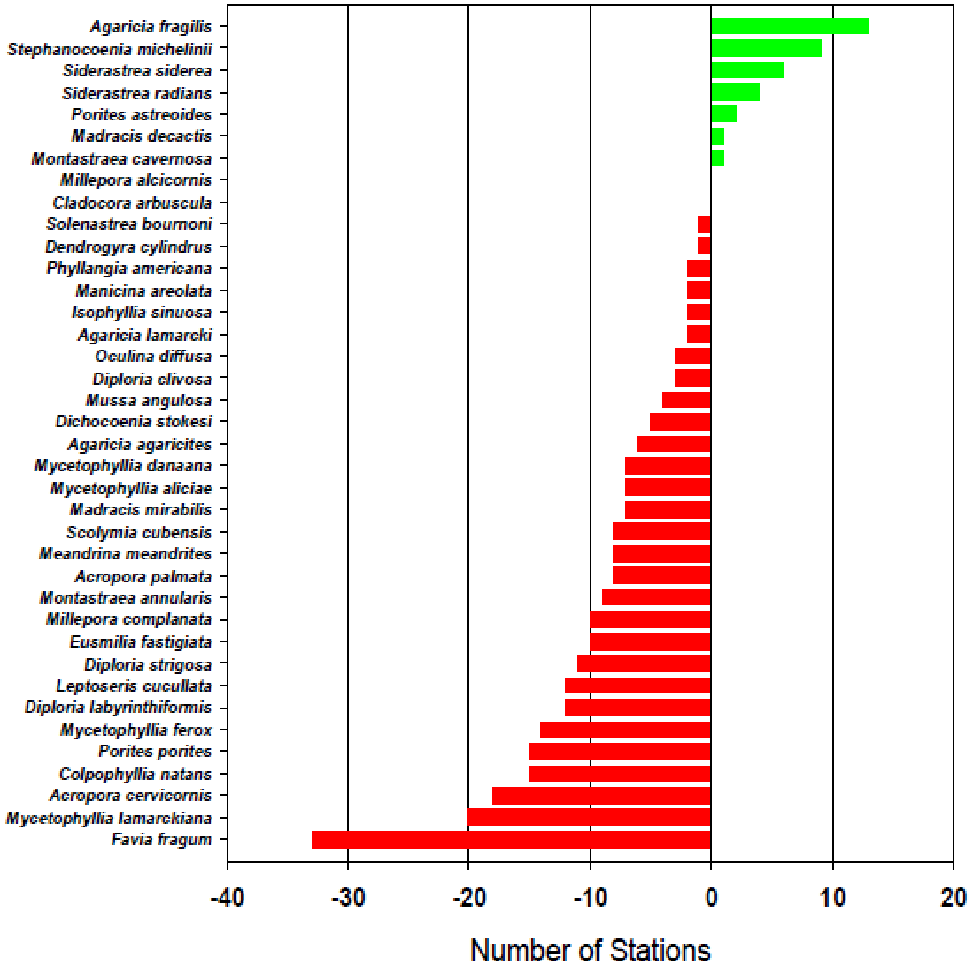

Figure 9. Change in the presence/absence (number of stations) of individual coral species from 1996 to 2008 in the Florida Keys (N=97 stations).

Figure 9-3. Graphical representation of the loss or presence of coral species from stations (Source: Ruzicka *et al.*, 2010, p 22).

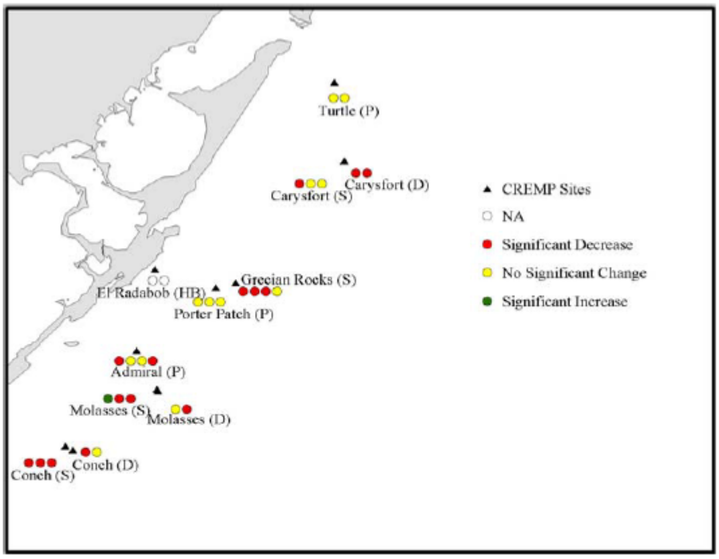

Figure 3. Distribution of significant change in stony coral cover at Upper Keys stations, 1996-2001 vs. 2002.

Figure 9-4. Summary of CREMP monitoring in the Sanctuary Science Report (Source: Keller & Donahue, 2006, p 71).

CASE STUDY 10: NOAA Coral Reef Conservation Program – Fish Monitoring, Florida Keys National Marine Sanctuary, U.S.A.

MPA: Florida Keys National Marine Sanctuary (NMS), Florida, U.S.A.

Managing Agency: National Oceanic and Atmospheric Administration, National Marine Sanctuaries (NOAA NMS) and the National Park Service (NPS)

Park details
See details in case study 9.

Within the Florida Keys NMS, a network of "no-take" marine reserves (NTMRs) were established in 1997 along the Florida Keys Reef Track east of Key West. This network is comprised of 22 Sanctuary Preservation Areas (SPAs), and a larger Western Sambo Ecological Reserve (WSER) (United States Department of Commerce 1996, Bohnsack *et al.* 2009). In the southern Florida coral reef, a no-take marine reserve (NTMR) was designated in 2007 in the western half of Dry Tortugas National Park. This covers 158 km^2 of prime shallow-water reef habitat. This NTMP was designed as a shallow-water complement to two relatively large NTMRs (Tortugas North and South Ecological Reserves), established in 2001 by NOAA in the Florida Keys National Marine Sanctuary (FKNMS) (Ault *et al.* 2006).

MPA conservation objectives
See Case Study 9.

Biological monitoring programmes
See Case Study 9.

<u>Monitoring Programme Case Study</u>
NOAA Coral Reef Conservation Program (CRCP), fish monitoring (Bohnsack *et al.* 2009) along the Florida Keys Reef Track east of Key West.

NB there is a separate monitoring programme for the Dry Tortugas National Park. Results from this monitoring programme are reported in a number of technical reports and scientific publications (e.g. Ault *et al.* 2006, Ault *et al.* 2008).

Who monitors
Scientists from the NOAA's Southeast Fisheries Science Center (SEFSC), Florida Fish and Wildlife Commission, National Park Service, and the University of Miami.

Primary contact
Dr Jim Bohnsack, Chief, Protected Resources and Biodiversity Division, Southeast Fisheries Science Center, NOAA

Professor Jerald S. Ault, University of Miami, Rosenstiel School of Marine and Atmospheric Science

Scott Donahue, Associate Science Coordinator, Florida Keys National Marine Sanctuary

Acknowledgement of MPA conservation objectives?
MPA conservation objectives are not explicitly stated in the monitoring technical report (Bohnsack *et al.* 2009).

APPENDIX 1 - CASE STUDY 10: NOAA Coral Reef Conservation Program – Fish Monitoring, Florida Keys National Marine Sanctuary, U.S.A.

Monitoring programme objectives

One aim of the SEFSC fish monitoring programme is to assess the effectiveness of the NTMRs by comparing trends in population metrics between areas closed and open to fishing for key exploited reef fish species and two non-exploited reef species.

Prediction (Hypothesis): The abundance of exploited species should increase in no-take reserves because of relaxed fishing pressure compared to similar habitat in fished areas subjected to fishing. Reference species not directly targeted by fishing are not predicted to increase directly in response to relaxed fishing pressure.

What is monitored

Exploited and non-exploited reef fish species (total numbers and numbers of spawning individuals).

Scale of the monitoring program

Spatial: Multiple sites within fished areas and reserves protected from fishing (22 SPAs and the WSE; 47,140 ha fished area and 2,930 ha no-take area).

Temporal: Annual surveys since 1994 (NTMRs established in 1997).

Monitoring design

Spatial replication:

- Multiple Sites monitored using stratified random sampling amongst habitat types (Patch Reefs and three types of Fore-reef), depths and management zones (fished areas and reserves protected from fishing).
- Sampling units: multiple 7.5 m radius circular plots within each Habitat and Site are used to count fish.

Temporal replication:

- Annual surveys before reserve establishment (1994-97) and ten years following reserve establishment (1998-2007). Surveys were generally conducted between May through August before hurricane disturbances.

Data collection method:

Reef fish Visual Census (RVC) methodology ("a standard non-destructive, fishery-independent, spatially-explicit monitoring method" (Bohnsack *et al.* 2009, Brandt *et al.* 2009)):

- In situ visual counts of reef fish by highly trained and experienced SCUBA divers within 7.5 m radius circular plots.

Statistical analysis used

<u>Assessment of temporal trends (evaluation of trends at MPA and Reference sites):</u>

- Time-series plots of the annual mean abundance (with 95% Confidence Intervals) of seven fish species targeted by fishing and two ecologically important parrotfishes, not targeted by fishing, as reference species for comparison purposes (see **Figure 10-1.** Time-series plots of a) the targeted yellowtail snapper, and b) the non-targeted striped parrot fish. 95% Confidence Intervals of baseline condition (1994-1997) are plotted as vertical lines, and represent the 'null model predictions' of no change from 'no-take' and fished areas. Significant differences between mean abundance and the null model prediction (baseline mean) are denoted by an asterisk. Red and black boxes indicate the scale (and potential impact) of hurricanes (Source: Bohnsack, 2009, p. 21).).
- Two temporal trends are shown for each species- one from fished areas and the other from reserves protected from fishing.

- 95% Confidence Intervals of baseline condition (1994-1997) are plotted as vertical lines, and represent the 'null model predictions' of no change following establishment of 'no-take areas' and fished areas.
- Mean abundances of each year at fished and reserve areas are compared to the null model prediction (baseline mean) and significant differences are denoted by an asterisk.
- The same time-series plots, with baseline condition (96% C.I.s) are used to plot the proportional abundance of spawning individuals in the 'no-take' areas.

Results to date

Bohnsack *et al.* (2009) were able to make strong conclusive statement based on their 10 years of fish monitoring in the Florida Keys NMS due to explicitly stating their hypothesis at the beginning of the report. They concluded: "Monitoring results in Florida Keys NMS no-take marine reserves were consistent with predictions of marine reserve theory. Density increased for the seven exploited species examined (three grouper, three snapper, and a wrasse) during the decade after reserves were established and no biologically significant increases were detected for two reference parrotfish species not targeted by fishing".

Non-technical summary reports also summarise the results of the SEFSC fish monitoring (Keller & Donahue 2006, Wusinich-Mendez & Trappe 2007).

Reporting style

Government technical/status reports (e.g. Bohnsack *et al.* 2009), scientific papers (e.g. Ault *et al.* 2006), and non-technical summary reports (e.g. Keller & Donahue 2006).

Reporting frequency and availability of reports

The SEFSC ten year report on the coral reef fish response to Florida Keys NMS (Bohnsack *et al.* 2009) is available on the Southeast Fisheries Science Center website, however this is not referred to on the Florida Keys NMS website. It was only through direct contact with the lead researcher (J Bohnsack) that I was made aware of this recent report.

The results from the SEFSC coral reef fish monitoring have been predominantly reported through scientific papers (e.g. Ault *et al.* 2006, Smith *et al.* 2011).

Non-technical summary reports (e.g. Keller & Donahue 2006) are due every five years, but one has not been published since 2006 (presenting monitoring results up to 2003). A newer 'Condition Report' for the Florida Keys NMS is due to be published by NOAA later in 2011 (S. Donahue pers comm.).

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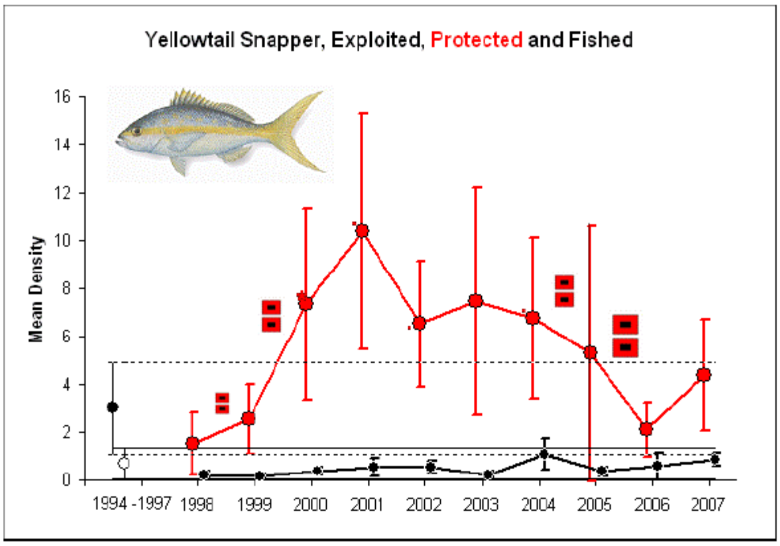
APPENDIX 1 - CASE STUDY 10: NOAA Coral Reef Conservation Program – Fish Monitoring, Florida Keys National Marine Sanctuary, U.S.A.

a)

Figure 2. Comparison of yellowtail snapper density trends in fully protected "no-take" Sanctuary reserves (SPAs and WSER, solid upper line) and exploited reference areas (dashed lower line). Vertical line shows when no-take protection initiated. Horizontal finely dashed (SPAs) and darker dashed (reference areas) bands show null model predictions based on 1994-1997 95% annual performance measures projected to 2003. Whiskers show 95% confidence intervals. Asterisks denote significantly different densities from the "no significant change" projection.



b)

Figure 10. Comparison of striped parrotfish density trends in fully protected "no-take" Sanctuary reserves (SPAs and WSER, solid upper line) and exploited reference areas (dashed lower line). Vertical line shows when no-take protection initiated. Horizontal dotted (SPAs) and dashed (reference areas) bands show null model predictions based on 1994-1997 95% annual performance measures projected to 2003. Whiskers show 95% confidence intervals. Asterisks denote significantly different densities from the "no significant change" projection.

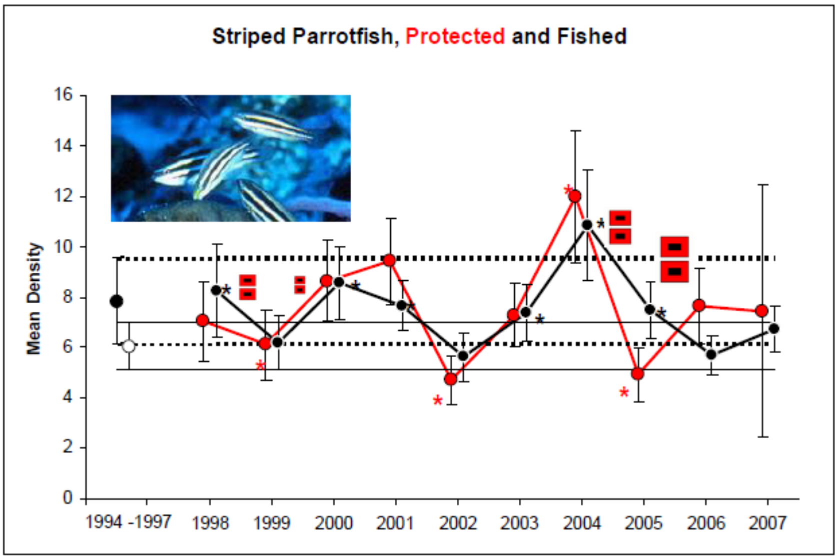


Figure 10-1. Time-series plots of a) the targeted yellowtail snapper, and b) the non-targeted striped parrot fish. 95% Confidence Intervals of baseline condition (1994-1997) are plotted as vertical lines, and represent the 'null model predictions' of no change from 'no-take' and fished areas. Significant differences between mean abundance and the null model prediction (baseline mean) are denoted by an asterisk. Red and black boxes indicate the scale (and potential impact) of hurricanes (Source: Bohnsack, 2009, p. 21).

CASE STUDY 11: Coral Reef Conservation Project Monitoring, Kenya's Marine National Parks, Africa

MPA: Malindi, Watamu and Mombasa Marine National Parks (MNPs), Kenya, Africa

Managing Agency: Kenya Wildlife Service (KWS)

Park details
Malindi and Watamu MNPs were established in 1968 and officially closed to fishing in the early 1970s, while the Mombasa Marine National Park was established in 1987 and officially closed to fishing in 1991 (Muthiga 2006, 2009).

The Mombasa Marine National Park (MNP) is a no-take area (1,000 ha) that is encompassed within a larger Marine Reserve (20,000 ha; Muthiga 2006). The Malindi and Watamu MNPs are 600 ha and 200 ha respectively and also both sit within larger Marine Reserves (sizes not known; Kenya Coast 2011).

MPA conservation objectives
The Kenyan MNPs have the objective to ensure the preservation and conservation of marine biodiversity (Muthiga 2009).

Biological monitoring programmes
The Wildlife Conservation Society's Coral Reef Conservation Project contributes most of the data needed on park ecology (DLIST 2010), and they monitor various aspects of the following biological communities:
- Coral communities (invertebrates, algae and fish)
- Seagrass communities (seagrass and fish)
- Fish (targeted and non-targeted)
- Fish herbivory and sea urchin predation

Monitoring Programme Case Study
Coral communities (invertebrates, algae and fish; McClanahan & Graham 2005, Muthiga 2006, McClanahan 2008a, b, Muthiga 2009)

Who monitors
The Wildlife Conservation Society, Coral Reef Conservation scientists (an independent long-term monitoring project led by Dr Tim McClanahan).

Primary contacts
Dr Tim McClanahan, Senior Conservation Zoologist, Wildlife Conservation Society Coral Reef Conservation

Dr Nyawira Muthiga, Director Kenya Marine Program/Conservation Scientist, Wildlife Conservation Society

Acknowledgement of MPA conservation objectives?
MPA conservation objectives have not been explicitly stated in any scientific papers (e.g. McClanahan & Graham 2005, McClanahan 2008b, McClanahan *et al.* 2008). Only the trial MNP evaluation system (Muthiga 2006, 2009) outlines the MPA conservation objectives in relation to the three biophysical indicators which are assessed.

APPENDIX 1 - CASE STUDY 11: Coral Reef Conservation Project Monitoring, Kenya's Marine National Parks, Africa

Monitoring programme objectives

To evaluate the effectiveness of Kenya's MNPs using three biophysical indicators (Muthiga 2006, 2009).

What is monitored

Key biological parameters analysed are:

- Hard coral cover (represents biophysical indicator: Habitat distribution and complexity)
- Finfish biomass of major families (represents biophysical indicator: Focal species abundances)
- Sea urchin biomass (represents biophysical indicator: Food web integrity)

Scale of the monitoring program

Spatial: Five sites within and seven sites outside of the MNPs (total 1,800 ha 'no-take' area).

Temporal: Surveys began at some of the MNPs in 1987, however Muthiga (2009) present annual data from 1993 – 2005.

Monitoring design

Spatial replication:

- Three protected reefs (Malindi, Watamu and Mombasa MNPs) and four unprotected reefs.
- Multiple sites were located within each reef: Malindi (two sites), Watamu (one site) and Mombasa (two sites). Seven sites were in the heavily fished reefs of Vipingo (two sites), Kanamai (two sites), Ras Iwatine (one site), and Diani (two sites).
- Sampling units: multiple transect/areas were surveyed within each site (see data collection method for details).

Temporal replication:

- Annual surveys from 1993 – 2005 (excluding 1998 and 2003), and is ongoing (T. McClanahan pers comm.).

Data collection method:

Visual census of coral cover, finfish abundance and sea urchin density, within the following sampling units:

- Coral cover: Multiple haphazardly-placed 10 m benthic line-intercept transects surveyed within each site.
- Finfish surveys: Multiple 100 m transects surveyed for 11 taxonomic categories of finfish (counts and size categories are estimated).
- Sea urchin density: Multiple 10 m^2 area(s) surveyed in each site.

Statistical analysis used

<u>Assessment of temporal trends</u> (evaluation of trends at MPA and Reference sites, as presented in Muthiga 2006, 2009):

- Temporal trends are plotted for hard coral cover, fish abundance and biomass and sea urchin density and biomass, and are shown for each MNP and Reference site (**Figure 11-1**). No statistical analysis done to assess temporal trends.
- The overall evaluation of each biophysical indicator was presented in a table format with a scoring system and included: a plus (+) sign indicating a positive trend, a minus (-) sign indicating a negative trend (see Table 11-1 **Overall evaluation of each biophysical indicator (Source: Muthiga, 2009, p.422).** (See **Table 11-1**)

NB: All other scientific papers produced used specific statistical analyses for their scientific question of interest. Temporal trends similar to what is presented in **Figure 11-1** (evaluating the effectiveness of MNPs) and in the 'Status of coral reefs of the world: 2008 report'

(Wilkinson 2008) have been reported by T. McClanahan (lead scientist) to the KWS informally each year, but no formal reports are written (as the monitoring is not funded by KWS; T. McClanahan pers comm.).

Results to date

- Positive MNP effects on finfish and sea urchins (finfish abundances and biomass remained high and sea urchin abundances and biomass remained low).
- The MNP effects on hard coral cover have been outweighed by the dramatic decline in hard coral cover due to the 1998 El Nino disturbance.

Reporting style

Only scientific papers are produced from the Kenyan MNPs (e.g. McClanahan & Graham 2005, McClanahan *et al.* 2007, McClanahan 2008b, McClanahan *et al.* 2008, Muthiga 2009) and occasional contributions to reviews (e.g. International Coral Reef Action Network 2004, Wilkinson 2008). Currently no government reports are produced, but the KWS are keen to develop a report card evaluation of their MNPs, and this is likely to follow the format of (Muthiga 2009; N. Muthiga pers comm.).

The WCS is currently writing a 20 year evaluation book based on the monitoring from Kenya's NMPs (T. McClanahan pers comm.).

Reporting frequency and availability of reports

Publication of monitoring results is primarily in scientific journals only.

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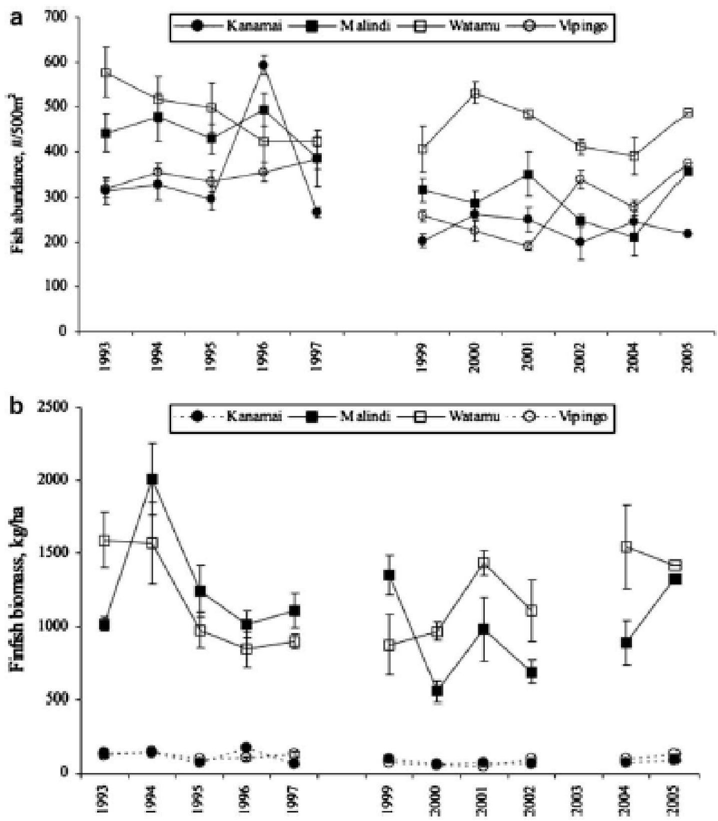

Fig. 2. (a) Coral reef finfish abundances (#/500 m^2) in the Malindi (solid square), Watamu (open square) marine parks and reference unprotected reefs in Kanamai (solid circle) and Vipingo (open circle triangle) from 1993 to 2005. Source: CRCP database. (b) Coral reef finfish biomass (kg/ha) in the Malindi (solid square), Watamu (open square) marine parks and reference unprotected reefs in Kanamai (solid circle) and Vipingo (open circle) from 1993 to 2005. Source: CRCP database.

Figure 11-1. Plots of temporal trends in fish abundance and biomass (Source: Muthiga, 2009, p 419).

Table 11-1 Overall evaluation of each biophysical indicator (Source: Muthiga, 2009, p.422).

Table 3
Summary of the scores for the parameters for each biophysical (B), socio-economic (S) and governance (G) indicators. Scores are based on the general direction of change. Two scores correspond to indicators that have more than one parameter.

Indicators	Score	Comment for each parameter
B1. Habitat	(−) (+)	Coral cover decreased dramatically due to bleaching related mortality and the recovery was slow. Topographic complexity remained high
B2. Focal species	(+) (+)	Coral reef finfish abundances and biomass remained high while sea urchin abundances and biomass remained low
B3. Food wed complexity	(+) (+)	Urchin predator abundances and biomass remained high and predation rates remained low
S1. Resource use	(+) (−)	Tourism's contribution to the boat operators in the MPAs was substantial. Parks are contributing to fish stocks as spillover but catch per individual fisher reduced possibly due to overfishing
S2. Community infrastructure	(+) (?)	MPAs invested in many initiatives to improve boat operator businesses. The exact contribution of tourism to the local community unknown
S3. Knowledge distribution	(+) (?)	MPAs had adequate infrastructure and programs for awareness. The impact of awareness programs unknown. There is a need for better coordination with researchers and NGOs
G1. MPA infrastructure and staff	(+) (−)	Park infrastructure and staff were adequate especially in Malindi. MPAs experience financial constraints despite high revenues; operational budgets need to be increased
G2. Regulations and enforcement	(−) (=)	Regulations specific to MPAs not gazetted, enforcement in parks was successful but surveillance and enforcement in the marine reserve needs to be improved
G3. Stakeholder participation	(−) (=)	No formal mechanism for community participation and Wildlife policy yet to be approved

APPENDIX 2 - MPA monitoring programmes considered for review, but not included as final case studies.

The primary reasons that these were not included as case studies included: long-term monitoring programmes exist but there are no publicly available monitoring reports or recent scientific papers; long-term monitoring programmes are currently being implemented and therefore have not been reported to date; or no long-term monitoring is conducted.

MPA and monitoring programme	**Management or monitoring agency**	**Comments**	**Evidence**
A2.1 Western Australia's Marine Protected Areas (e.g. Ningaloo Reef), Australia	Department of Environment and Conservation	Western Australian Marine Monitoring Program (WAMMP) is currently being developed (Department of Environment and Conservation 2010). This will be an integrated long-term, state wide marine protected area and threatened marine fauna monitoring program in Western Australia's coastal waters. Other long-term monitoring programmes which exist, but assessments/reporting of the monitoring results are not publicly available: • A long term monitoring programme of the proposed Dampier Archipelago Marine Park which commenced in 2007 (Hirst 2008, Armstrong 2009a). • Ningaloo Marine Park Drupella long-term monitoring program which commenced in 1989 (Hirst 2008, Armstrong 2009b). The lack of reporting of Western Australia's MPA monitoring results means that this cannot be considered as a case study for this review.	Email contact with Dr Kim Friedman, Principal Research Scientist, Marine Science Program (Monitoring), Department of Conservation, Western Australia
A2.2 South Australia's Marine Parks	Department of Environment and Natural Resources (DENR)	A system of marine parks is currently being established in South Australia. The DENR has asked to receive details of these Parks within the first half of 2011, following this draft management plans will be developed with zoning prior to formal community consultation in the second half of 2011. As no monitoring currently exists, the South Australian MPs cannot be considered as a case study for this review.	Email contact: Sarah Bignell, Marine Scientist, DENR

APPENDIX 2 – MPA monitoring programmes considered for review, but not included as final case studies

MPA and monitoring programme	Management or monitoring agency	Comments	Evidence
A2.3 Coral Triangle Initiative, system of Marine Protected Areas in Indonesia, Philippines, Eastern Malaysia, Papua New Guinea, Timor Leste and the Solomons	Coral Triangle Centre	The Coral Triangle was initiated in an attempt to reverse the degradation of these reefs at the global centre of reef biodiversity (Wilkinson 2008). The initiative was launched in 2006, and the Nature Conservancy with local and international partners (Coral Triangle Centre) are working to establish large-scale networks of marine protected areas (MPAs). Biological monitoring methods for assessing coral reef health and management effectiveness of Marine Protected Areas in Indonesia were written in 2009. No monitoring assessments are available to date. For these reasons, this cannot be considered as a case study for this review.	Email contacted Alison Green and Joanne wilson, The Nature Conservancy
A2.4 Apo and Sumilon Islands Marine Reserves, Philippines	Department of the Environment and Natural Resources	This is one of six MPA monitoring programmes (Apo Islands) in the world which has over a decade's worth of data (Babcock *et al.* 2010). There have been a number of publications highlighting the long-term monitoring results from the Sumilon and Apo Island MPAs (e.g. Russ & Alcala 2003, Alcala *et al.* 2005, Russ & Alcala 2010), however no papers have presented recent data from the long term monitoring programme in evaluating the effectiveness of these MPAs. There is a ReefCheck monitoring programme at Apo Island Marine Reserve, but the level of detail provided in the reports (e.g. Raymundo 2009) is not adequate to be included as a case study in this review.	Attempted email contact (but no response): Prof Garry Russ, James Cook University, Australia

APPENDIX 2 – MPA monitoring programmes considered for review, but not included as final case studies

MPA and monitoring programme	Management or monitoring agency	Comments	Evidence
A2.5 Mediterranean Marine Protected Areas	A number of management agencies – see Abdulla *et al.* (2008)	A number of scientific studies have focused on the effects of MPAs (e.g. Claudet & Guidetti 2010), but the vast majority of these are short term (2-3 years; J. Claudet, pers comm.). Many of these scientific studies are reviewed in recent papers (e.g. Garcia-Charton *et al.* 2008, Lester *et al.* 2009, Stewart *et al.* 2009, Claudet & Guidetti 2010), but the existence of any government long-term monitoring is not mentioned in the scientific literature and has not been revealed in internet searches. This is confirmed by Abdulla *et al.* (2008) who stated that habitats and species monitoring is not common practice for Mediterranean MPAs. Additionally, websites and government publications could not be effectively searched as these were not in English. For these reasons, this cannot be considered as a case study for this review.	Email contact with: Joachim Claudet, University of Perpignan, France Paolo Guidetti, University of Salento, Italy
A2.6 United Kingdom's MPAs	Joint Nature Conservation Committee	The UK has only a very small proportion of 'no-take' MPAs (a 3 km² Marine Reserve off Lundy), the remainder of the MPAs around the UK are considered 'multiple-use' (United National Environment Programme - World Conservation Monitoring Centre 2008). Blyth-Skyrme *et al.* (2006) have conducted an evaluation of the conservation benefits of temperate marine protected areas, however this is based on fisheries catch data (this therefore failed to meet the criteria of this review, as data had to be based on visual census rather than fisheries catch data). Other long-term monitoring has been conducted in places such as the Skomer Island Marine Reserve, and small reports are available on the Countryside Council for Wales (CCW) website however these were not detailed enough for inclusion as a case study in this review.	Dr Bill Sanderson, Reader, Heriot Watt University, Edinburgh, UK.

APPENDIX 2 – MPA monitoring programmes considered for review, but not included as final case studies

MPA and monitoring programme	**Management or monitoring agency**	**Comments**	**Evidence**
A2.7 Canary Islands Network for Protected Natural Areas, Africa (Spanish Territory)	Red Canaria de Espacios Naturales Protegidos	Some publications on MPA effects exist for the Canary Islands (Clemente *et al.* 2009, Tuya *et al.* 2006), however there is no evidence of long-term monitoring programmes. Additionally, websites and government publications could not be effectively searched as these were not in English. For these reasons, this cannot be considered as a case study for this review.	Attempted email contact (but no response): Dr Fernando Tuya, Center for Ecosystem Management, Edith Cowan University
A2.8 iSimangaliso (formerly Greater St. Lucia) Wetland Park, South Africa	A UNESCO World Heritage Site managed by Ezemvelo KwaZulu-Natal Wildlife (EKZNW)	Long-term monitoring programme (led by Dr. Michael Schleyer; e.g. Schleyer & Celliers 2005, Schleyer *et al.* 2008a, Schleyer *et al.* 2008b) has been conducted since 1993 to determine the effects, of climate change on high-latitude coral reefs within the Marine Park. This research is conducted within a MPA, but it is not focused on evaluating the effectiveness of the MPA. For these reasons, this cannot be considered as a case study for this review.	Email discussions with Dr. Michael Schleyer, Oceanographic Research Institute (key scientist involved in monitoring iSimangaliso Wetland Park).
A2.9 Galapagos Marine Reserve	Charles Darwin Foundation	Charles Darwin Foundation (CDF) have conducted a Subtidal Ecological Monitoring (lead scientist Dr Stuart Banks) since 2000. The initial stages of this monitoring have been reported (e.g. Edgar *et al.* 2004, Edgar *et al.* 2008) and there are CDF technical reports based on single years worth of data (e.g. Charles Darwin Foundation 2010). The results of this long-term monitoring are currently being assessed, and due to be published in mid 2011. It is for these reasons that this cannot be included as a case study.	Email discussions with: Graham Edgar, Tasmanian Aquaculture and Fisheries Institute Stuart Banks, Charles Darwin Foundation

APPENDIX 2 – MPA monitoring programmes considered for review, but not included as final case studies

MPA and monitoring programme	Management or monitoring agency	Comments	Evidence
A2.10 Canada's National Marine Parks	Parks Canada	An ecologically representative network of National Marine Parks will be established in Canada by 2012. Some National Marine Parks already exist (Fathom Five National Marine Park, Ontario, and Saguenay-St. Lawrence Marine Park in Quebec), but these have no publicly available reports on the evaluation of marine biological monitoring. Only one Status Report was found for the Pacific Rim National Park Reserve of Canada (2009), which presents a small amount of marine monitoring results. This was therefore not considered as a case study in this review.	Email contact with Parks Canada staff: Scott Parker, Fathom Five National Marine Park Norm Sloan, Gwaii Haanas National Park Reserve
A2.11 Las Cruces Marine Protected Area, Chile	The Marine Subsecretary (within the Ministry of National Defense) (The Nature Conservancy 2008)	Las Cruces is considered the only existing and effective marine reserve in Chile for which there is ecological information and long-term monitoring (Navarrete *et al.* 2010). Humans (other than research scientists from the Catholic University of Chile) have been excluded from this intertidal rocky reef since 1982, making Las Cruces an ideal location to demonstrate the effect of removing humans as predators from an intertidal system (Castilla & Duran 1985, Duran & Castilla 1989, Fernandez & Castilla 2005, Castilla *et al.* 2007, Fernández 2008, Navarrete *et al.* 2010). There are no scientific papers presenting a detailed assessment of recent monitoring data. Additionally, websites and government publications could not be effectively searched as these were not in English. For these reasons, this cannot be considered as a case study for this review.	Attempted email contact (but no response): Dr Miriam Fernandez, Associate Professor, Catholic University of Chile

APPENDIX 2 – MPA monitoring programmes considered for review, but not included as final case studies

MPA and monitoring programme	Management or monitoring agency	Comments	Evidence
A2.12 Mesoamerica Reef, South America	The multi-organizational Healthy Reefs for Healthy People (HRHP) Initiative.	The HRHP Initiative has developed a Report Card for the Mesoamerica Reef (HRHP 2010) based on 24 biological indicators which contribute to the two (Ecosystem Structure and Ecosystem Function) of the four main components which are used in the Report Cards to assess the 'health' of the Mesoamerican Reef (McField & Richards Kramer 2007). No reports/papers which detail results from marine monitoring that informed the Report Card can be found. The large scale monitoring programme which is thought to be associated with the HRHP Report Card is the Mesoamerican Barrier Reef Systems (MBRS) project Synoptic Monitoring Program (SMP), which is considered an example of new applications to assess coral reefs and associated ecosystems which is being applied in MPAs to gather reliable data on reef status based on standardized monitoring methods (Wilkinson 2008). To date the results of this monitoring programme have been extremely limited (Garcia-Salgado *et al.* 2008, García-Salgado *et al.* 2008), and therefore the SMP cannot be presented as a case study in this review. There was some difficulty in effectively searching websites and technical publications, as some of these were not in English. For all of these reasons, this cannot be considered as a case study for this review.	Email contact: Miguel García, Oceanus, SMP scientists Attempted email contact (but no response): general email account for HRHP

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APPENDIX 3 - Marine environmental impact assessment examples

Examples of monitoring design and statistical analysis used to assess the impact of the most common environmental impacts to the marine environment over the past two decades.

Marine environment impact assessment examples	**Monitoring Design**	**Univariate analysis**	**Multivariate analysis**
Oil spills			
The effect of the Prestige oil spill on macrobenthic infauna, Iberian Peninsula, Spain (Serrano *et al.* 2006)	After sampling at different distances away from the impact (gradient)	Correlations between environmental variables (including latitude) vs biological indicators	-
The effect of the Aegean Sea oil spill on macrobenthic infauna, Ares-Betanzos Ria, Spain (Gesteira & Dauvin 2005)	Before After Impact	t-test and Pearson correlation coefficient to compare temporal trends	nMDS PCA
The effect of the Exxon Valdez oil spill on seabirds, Prince William Sound, Alaska (McDonald *et al.* 2000)	Before After Control Impact	Repeated measures ANOVA	-
The effect of the Exxon Valdez oil spill on macrobenthic infauna associated with eelgrass beds, Prince William Sound, Alaska (Jewett *et al.* 1999)	After Control Impact	ANOVA	nMDS Discriminant analysis (examines the degree to which key environmental variables can discriminate between biological variables)
The effect of an oil spill on macrobenthic infauna, Bay of Morlaix, France (Clarke & Warwick 1998)	Before After Control Impact	-	nMDS
The effect of the Braer oil spill on macrobenthic infauna, Shetland Islands, United Kingdom (Kingston *et al.* 1995)	After sampling at different distances away from the impact (gradient)	-	nMDS ANOSIM
Outfalls			
The storm water effects on algal epifauna, New South Wales, Australia (Roberts *et al.* 2007)	Before After Control Impact	ANOVA	

Marine environment impact assessment examples	**Monitoring Design**	**Univariate analysis**	**Multivariate analysis**
Outfalls continued			
The urban runoff effects from contaminated estuaries on benthic macrofauna, Auckland, New Zealand (Morrissey *et al.* 2003)	After sampling at different distances away from the impact (gradient)	ANOVA	nMDS ANOSIM SIMPER Canonical correspondence analysis (biology vs environmental variables)
Outfall impacts on subtidal benthic rocky reef assemblages, New South Wales, Australia (Roberts *et al.* 1998)	Before After Control Impact	ANOVA with Student-Newman-Keuls (SNK) comparisons	nMDS plots ANOSIM SIMPER
The effect of heated water outfalls on kelp forest algal assemblages, San Onofre Nuclear Generating Station, California, United States of America (Schroeter *et al.* 1993)	Before After Control Impact	ANOVA and t-tests	-
Other disturbance			
The effect of offshore gas field platforms on macrobenthic infauna, Crotone, Italy (Terlizzi *et al.* 2008)	After sampling at different distances away from the impact (gradient)	ANOVA	PERMANOVA nMDS SIMPER PERDISP
The impact of dredged material disposal on intertidal and subtidal benthic communities, England and Wales, United Kingdom (Bolam *et al.* 2006)	Impact sites (after only)	ABC – abundance Biomass Comparison	nMDS BIOENV
The effect of human trampling on intertidal algae, Victoria, Australia (Keough & Quinn 1998)	Before After Control Impact	Repeated measures ANOVA	-
Impacts of pontoon installation on fish and benthic coral reef assemblages, Great Barrier Reef Marine Park, Queensland, Australia (Nelson & Mapstone 1998)	Before After Control Impact	ANOVA	-
The effect of marina development on epibiota in marinas, New South Wales, Australia (Glasby 1997)	Before After Control Impact	Asymmetrical ANOVA (with pooling)	-

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APPENDIX 4 - Background to issues with statistical inference – Type I and II errors, power and effect size

In the past few decades marine scientists have heavily relied on frequentist statistical tests to formally assess patterns observed in the marine environment (e.g. Underwood 1990). During this time however, a small contingent of concerned marine ecologists and statisticians have highlighted some serious pitfalls associated with the use of statistical significance testing. These pitfalls are referred to as Type I and II error rates, and can lead to incorrect conclusions about patterns in the marine environment (Green 1979, Fairweather 1991, Mapstone 1995, Underwood 1997b, Quinn & Keough 2002).

A Type I error is where a significant effect has been detected, when in fact one has not occurred (Green 1979, Underwood 1997b, Quinn & Keough 2002, Underwood & Chapman 2003). This is equal to the significance level (α or p-value) of the test which is conventionally set at 0.05. With a Type I error of 0.05, this means there is a 5% chance of detecting a significant difference, when in fact one has not occurred. That is, if a study consists of 20 significant effects ($p\text{-value} < 0.05$), one of these significant effects is incorrect (also known as a false positive).

A Type II error is where no significant effect has been detected, when in fact one has occurred. The value of a Type II error is more complex, and is inversely related to statistical power. The power of a test incorporates the variation inherent in the system being monitored, effect size to be detected, the sample size, and the significance level of the test (Green 1989, Fairweather 1991, Osenberg *et al.* 1994, Mapstone 1995). That is, all non-significant effects (p- value > 0.05) in a study have the potential to be incorrect (also known as a false negative) unless there is high power associated with the non-significant effect. Type II error rates can be very high if not controlled for by the researcher (Fairweather 1991).

The consequences of Type I and II error rates for environmental management are very different (Fairweather 1991, Underwood & Chapman 2003, Fidler *et al.* 2006). A Type I error will cause a management response of fighting a false alarm – this is likely to only continue in the short-term until the mistake is discovered; whereas a Type II error will result in a much higher environmental cost of not implementing a management response when in fact there should have been one. Having a high Type II error rate (or low power) can be disastrous for environmental monitoring programmes (Fairweather 1991, Underwood & Chapman 2003, Fidler *et al.* 2006).

Increased consideration of statistical power has been promoted as a solution to dealing with Type II error in current statistical practice in marine ecology (Fairweather 1991, Mapstone 1995, Underwood 1997a, Carey & Keough 2002, Downes *et al.* 2002, Quinn & Keough 2002, Underwood & Chapman 2003, Keough *et al.* 2007). The power to detect a significant effect in a statistical test depends on the variation in the dataset (standard error), the replication in the monitoring programme (sample size), the chosen Type I error rate and the magnitude of difference to be detected (the effect size) (Quinn & Keough 2002).

Power should be considered before a monitoring programme begins (‘*a priori*’), as this helps acknowledge the variability inherent in the system that is being monitored and helps articulate the predicted effect size of a hypothesised effect on a species. Variability in a system is often determined through a pilot survey, or from prior monitoring programmes conducted in the area. The most useful aspect of considering power ‘*a priori*’ is that the replication required in a monitoring program can be calculated (Fairweather 1991). The importance of considering power ‘*a priori*’ is discussed in general terms by many scientists (e.g. Green 1989, Fairweather 1991, Mapstone 1995, Underwood 1997a). However in practice there is very little evidence in the scientific literature that scientists, even in experimental marine ecology and EIA, consider power '*a priori*' (Fairweather 1991, Fidler *et al.* 2006). This is often because the marine systems which we are monitoring are often claimed to be poorly understood (Underwood 1998).

Power can also be considered (and calculated) at the data analysis stage of a monitoring programme (*'post hoc'*) to aid in the interpretation of non-significant results (Andrew & Mapstone 1987, Peterman 1990, Fairweather 1991, Thomas 1997). In the field of marine ecology, the power of a non-significant result should be at least 0.8 to avoid the potential of a Type II error (Fairweather 1991, based on the original recommendation by Cohen 1988). To date, there remains limited use of '*post hoc*' power calculations to aid in the interpretation of non-significant results in scientific literature (Toft & Shea 1983, Peterman 1990, Fairweather 1991, Fidler *et al.* 2006).

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