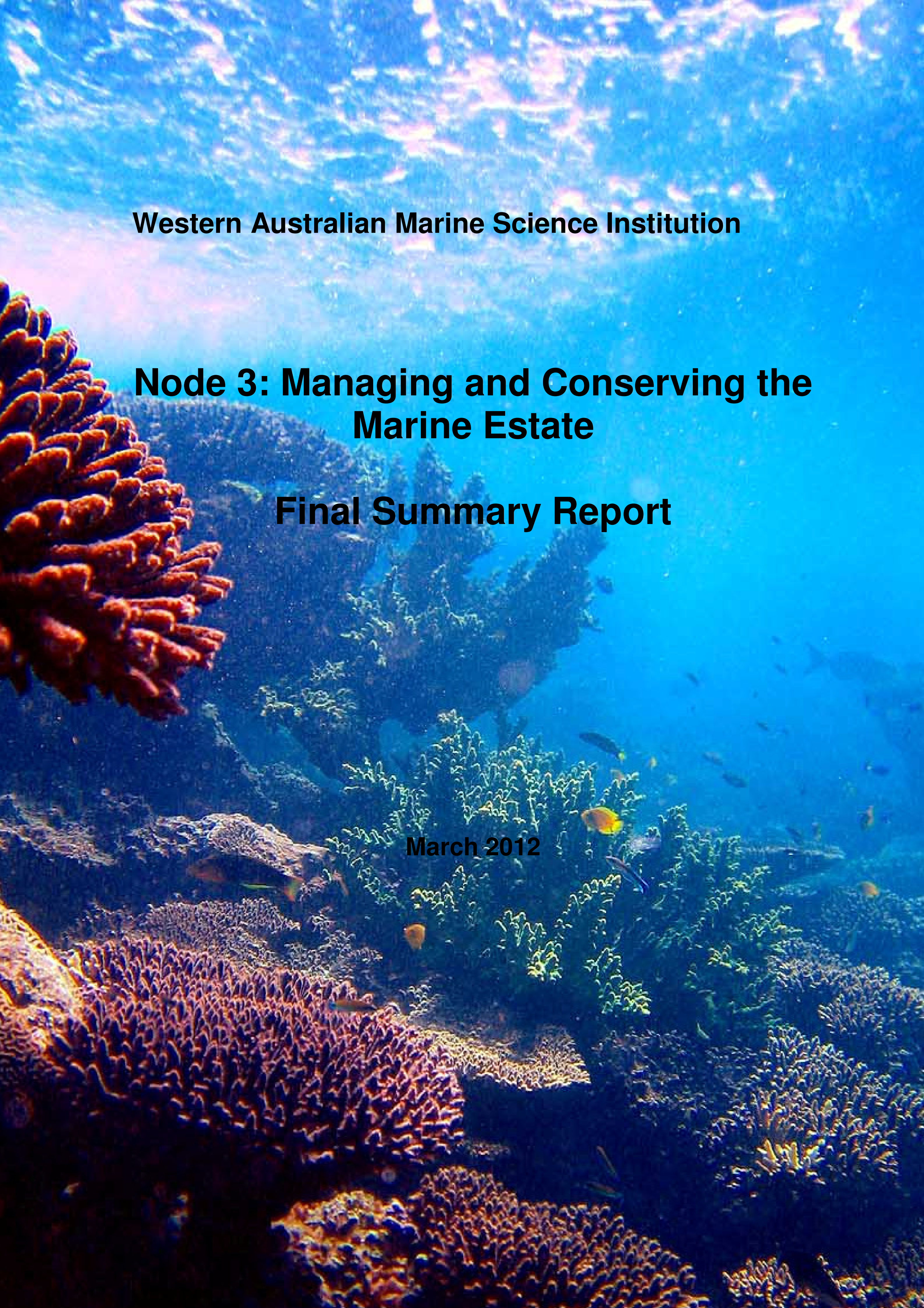
Western Australian Marine Science Institution

Node 3: Managing and Conserving the Marine Estate

Final Summary Report

March 2012



Cover photograph: An array of fish and coral in Ningaloo Marine Park, Western Australia. Courtesy of DEC.

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WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION

NODE 3 – MANAGING AND CONSERVING THE MARINE ESTATE

FINAL SUMMARY REPORT

March 2012

Prepared by:

Dr Chris Simpson and Dr Kelly Waples
Marine Science Program, Department of Environment and Conservation

ACKNOWLEDGEMENTS

Many people have contributed to the establishment and implementation of the management portfolio that comprised Node 3 of WAMSI from its inception in 2005 through to the culmination of the research and final reports in 2011. We would like to thank all the individuals and organisations who have participated in the planning and the research for their contributions to science and to the long term sustainability of Ningaloo Marine Park. In particular, we would like to thank Nick D'Adamo for his instrumental work in establishing the science plan for Node 3 of WAMSI and ensuring the research was not only targeted for management needs, but expanded through complementary programs such as the CSIRO Wealth from Oceans National Research Flagship program. Similarly, we thank the CSIRO Wealth from Oceans Flagship Program and all the participants of the Ningaloo Collaboration Cluster for their valuable contributions to our understanding of the values and their management at Ningaloo Marine Park. We would also like to thank the key participants in the coordination and integration of this research program, including Prof. Neil Loneragan, Dr Andrew Heyward and Dr Bill de la Mare, as their efforts have ensured that the knowledge gained from individual research projects has created a whole vastly larger than the sum of its many parts. Wendy Steele and Irene Abrahams have provided support for the integration process and communication activities throughout the program. A number of DEC staff have had a integral role to play in assisting with field logistics in the region as well as the working through the knowledge transfer elements of the research program. We would like to the thank the staff of DEC Exmouth District and all those who have participated in the meetings and workshops on knowledge transfer. We would also like to thank the staff the members of WAMSI that have supported Node 3 and provided much appreciated assistance with key tasks, including WAMSI CEO Dr Steve Blake and WAMSI support staff, Linda McGowan, Lynne Stephenson and Sue McKenna.

Finally, we would like to thank all of the research scientists from their many research organisations and institutions who have participated in the Node 3 research program as they are the main contributors to our new store of knowledge on Ningaloo Marine Park.

We would like to thank the following partner organisations for their financial and intellectual support to WAMSI Node 3 and the Ningaloo Collaboration Cluster:

WAMSI Node 3
Australian Institute or Marine Science
BHP Billiton
CSIRO
Curtin University of Technology
Department of Fisheries, WA
Edith Cowan University
Murdoch University
University of Western Australia
Western Australian Museum

Ningaloo Collaboration Cluster
Australian National University
CSIRO
Curtin University of Technology
Edith Cowan University
Murdoch University
Sustainable Tourism CRC
University of Queensland
University of Western Australia
Wealth from Oceans National Research Flagship

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EXECUTIVE SUMMARY

In 2005, the WA Government, in recognition of the importance of Ningaloo Reef allocated $5 million for research to support management of Ningaloo Marine Park. This program was incorporated in the broader WAMSI research program in 2006 as Node 3 and attracted significant co-investment, not only from WAMSI partners, but also through the development of the complementary Ningaloo Collaboration Cluster, a program of research funded by the CSIRO Wealth from Oceans National Research Flagship. The core funding of $5 million for WAMSI Node 3 and $2.5 million for the Ningaloo Collaboration Cluster was supplemented with co-investment including additional funds and in-kind support from CSIRO, AIMS, Department of Environment and Conservation, Department of Fisheries, Western Australian Museum, University of Western Australia, Curtin University of Technology, Edith Cowan University, BHP-Billiton and the Sustainable Tourism Cooperative Research Centre. This collaboration, along with additional external research leveraged the original $5 million of State funding into $36 million in cash and in-kind support between 2005 and 2011.

The research program was based on information needs identified in the Management Plan for the NMP and the Muiron Islands Marine Management Area 2005-2015 (CALM 2005) across the following general themes:

- improved bio-physical inventories and associated biodiversity assessments;
- improved characterisation and predictive capacity of the nature and levels of human usage;
- improved characterisation and modelling capacity of key ecological processes (focusing on bio-physical oceanography);
- development of cost-effective reef health indicators and monitoring protocols, focusing on coral and fish recruitment, and herbivory;
- characterisation and assessment of the ecosystem impacts of human usage, and an assessment of the effectiveness of the park's zoning for biodiversity conservation; and
- development and application of a multiple-use Management Strategy Evaluation framework to assess a range of development scenarios and to evaluate alternative management strategies to meet both conservation and socio-economic objectives.

The research program in Ningaloo Marine Park is the largest undertaken in the Indian Ocean Region for coral reef environments and is similar in effort and intensity to research programs undertaken within the Great Barrier Reef Marine Park, although at a smaller spatial scale. The combined research program of over 150 projects has generated a fundamental (at least 10-fold) improvement in knowledge and understanding of the physical and biological processes that maintain Ningaloo Reef and of the uses, values and impacts of humans that utilise the region.

A much more comprehensive baseline of knowledge and data for Ningaloo Marine Park has now been established, against which to measure future change, whether from direct or indirect human actions, including climate change. The effects of this investment will be felt for years to come, through the publication of results, the application of knowledge to management decision-making and through better community understanding of the ecological processes and effects of human use on the resources of the marine park. Such understanding should assist government, industry and community to address any future challenges to values, uses and conservation of this iconic place.

The research undertaken has contributed substantially to the declaration in June 2011 of the Ningaloo Coast as a World Heritage Area, in recognition of its status as a biodiversity 'hotspot' as well as an iconic destination for local, State, Australian and international tourists.

There is now a far better understanding of the physical and biological features that comprise Ningaloo Marine Park. This includes background and baseline information on the physical structure of the reef along with its history and growth and the type and distribution of benthic habitats and associated faunal communities inshore and offshore and latitudinally. The diversity, abundance and distribution of many species that inhabit NMP including intertidal invertebrates, target fish species and sharks are much better understood. Knowledge of the ecological and physical processes that support the reef system has improved markedly, including oceanic currents and local hydrodynamic regimes that bring nutrients to the reef in the form of phytoplankton. The whole marine park and adjacent coastal areas has now been mapped intensively including the distribution and characteristics of the seabed and sediments using a variety of methods. There is now a detailed data set that allows for modelling the trends and changes in key indicators over future years.

The physical and biological research at Ningaloo Marine Park shows unique distributions of the biodiversity with profound implications for the management of the region. As expected, biodiversity and species assemblages vary with water depth and habitat (i.e. the lagoon system contains different species assemblages to the reef slope, reef crest and deeper waters seawards of the reef). However, latitudinal differences in assemblages of plants and animals are indicative of a strong north-south gradient within Ningaloo Marine Park. Ningaloo Marine Park is exposed to both tropical and temperate oceanographic influences which, combined with variations in topography and geomorphology of the region, have produced very different species assemblages in the northern and southern ends of the Ningaloo Marine Park. An example is the distribution of rock lobster species. One temperate species dominates in the southern end of the marine park whereas in the north four tropical species are more commonly found.

Point Cloates in the centre of Ningaloo Marine Park stands out as a broad transition area from tropical to sub-tropical influence but also contains its own unique biodiversity and assemblages due to unique oceanographic conditions and the complex habitats created by a series of pinnacles and ridges on the seabed. This variation in species distribution throughout the park has very important management implications and in particular, the management of biodiversity values. Zoning plans and other management arrangements will need to provide adequate protection for the different biodiversity assemblages throughout Ningaloo Marine Park. Temperate and tropical species may be at the boundary of their range and the habitat in Ningaloo Marine Park may be sub-optimal for a number of species. The unique gradient of species and assemblages at Ningaloo Marine Park provides an ideal location for monitoring potential effects of climate change on key species and their environment.

Modelling exercises undertaken as part of the combined Ningaloo research programs have produced tools that will be valuable aids to management decisions and community consultation. Simulation techniques known as Management Strategy Evaluation (MSE) were used to explore the effectiveness of current management arrangements, and the consequences of alternative management actions and alternative future scenarios. One of the simulation models, the Effects of Line Fishing Simulator (ELFSim), was applied to the management of a major recreational fishing target species spangled emperor (*Lethrinus nebulosus*). Stakeholder workshops applied the model to possible future management actions, given a range of alternative ecological and socio-economic objectives. This process evaluated the effectiveness of current management arrangements, clarified tradeoffs inherent in pursuing different ecological and social objectives, and examined alternative future scenarios for management of Ningaloo Marine Park and its recreational uses, in the context of climate change.

The research has also examined the level of human impact on the resources and values of Ningaloo Marine Park and effectiveness of current management strategies. In general terms Ningaloo Marine Park is a relatively pristine coral reef environment; however human uses have had some significant impacts from fishing, recreation and tourism.

The new knowledge provided by this research program will support current management activities, and be important in future planning reviews to ensure the long-term conservation of Ningaloo Marine Park. In summary, the principle outcomes from this component of WAMSI research are:

- Significantly enhanced capacity to manage current human use of biodiversity assets and to evaluate future risks in Ningaloo Marine Park, including risks from climate change;
- Improved predictive capacity and scenario planning for future marine park management, tourism planning and fisheries management;
- Improved capacity to deliver efficient and effective conservation and management programs in Ningaloo Marine Park and other marine parks for government, through the development of indicators, monitoring protocols and management effectiveness evaluation models;
- Greatly enhanced (at least 10-fold) scientific knowledge to underpin the future management of Ningaloo Marine Park;
- Enhanced research effort in Ningaloo Marine Park through collaboration with other initiatives and programs; e.g. Ningaloo Collaboration Cluster, IMOS, C-Reefs, AATAMS, Geoscience Australia;
- Improved community awareness and support for government conservation and management programs in Ningaloo Marine Park through training and involvement in research, new tools and communication about research purpose and results (e.g. workshops in Perth and Ningaloo region, MSE discussions with community, researchers, managers and industry);
- The development of the Ningaloo Atlas, an interactive web-based tool, that will utilise the data sets from the Ningaloo Research Program and make them publicly available to anyone who wishes to use them;
- Development of improved links and collaboration between government research institutions, universities, government agencies, NGOs, industry and other end users;
- Enhanced ability to apply learning from Ningaloo Marine Park to other marine conservation and tourism management scenarios throughout the State; and
- Enhanced research capacity in Western Australia that will deliver returns in future years through students supported under the program.

The key outcomes, implications of research findings for management and recommendations from the research program are outlined in Sections 3, 4 and 5 of this report. The recognition of these outcomes and implementation of the recommendations, particularly those related to knowledge transfer, will be critical to the on-going use of this new knowledge in the conservation and management of Ningaloo Marine Park.

The new knowledge gained in the research program has already had application in the 'day to day' management of the Ningaloo Marine Park in numerous ways. Some of the many examples include:

- *Improved oil spill response planning and management* - based on better understanding of ocean current patterns, better predictions of oil spill trajectories and relative sensitivity and vulnerability of biodiversity assets to oil spills;
- *Improved efficiency of compliance programs* - based on a better understanding of human use patterns and the relative vulnerability of different biodiversity assets of the marine park to this use;
- *Improved effectiveness of mooring and anchoring plans* - based on a better understanding of visitor needs and the location and sensitivity of marine habitats to mooring and anchoring;
- *Improved management of visitor risk* – based on a better understanding of the relationship between wave height and dangerous ocean current conditions and when and where these conditions occur;
- *More effective license conditions for commercial tourism operators* - based on a better understanding of visitor requirements and preferences, human use patterns and trends and the location and sensitivity of marine biodiversity assets to these uses;
- *Enhanced efficiency and effectiveness of ecological and social monitoring, evaluation and reporting programs* – based on the development of cost-effective indicators and protocols;
- *Improved visitor infrastructure planning* - based on improved understanding of visitor values, aspirations, requirements and preferences;
- *Improved scientific knowledge base to support world heritage listing* – based on better descriptions and understanding of the global conservation significance of the marine biodiversity assets of the marine park;
- *Improved community understanding and acceptance of the difficulties in managing iconic marine areas* – based on an enhanced local community understanding of the complexity of the human-environment interactions; and
- *More targeted education and public participation programs* – based on improved understanding of the current impacts of human use and the reasons for these impacts and the enhanced appreciation of the desire for and benefits of community involvement in conservation and management programs.

Longer-term, the significantly improved scientific knowledge base and understanding now available to the managers and users of Ningaloo Marine Park will be used in planning further development along the Ningaloo coast and in planning and managing future recreational and commercial use of the waters of Ningaloo Marine Park. The new knowledge will also be the major source of scientific information for the periodic management audits by the MPRA and the reviews of the marine park management plan over the next 10-20 years. Together the short and longer-term use of this new knowledge will, hopefully, ensure the long-term conservation and sustainable use of Ningaloo Marine Park.

Administration of WAMSI Node 3

Node 3 - Managing and Conserving the Marine Estate: 'best practice' management and underpinning science.

Node Leader: Dr Chris Simpson, Program Leader, Marine Science Program, DEC

Science Coordinator: Dr Kelly Waples, Marine Science Program, DEC

Total Node Funding: $4,850,000[1]

Node 3 Science Plan
Major Projects and Project Leaders in bold, sub projects in normal text.

Ref No.	Project Title and Leader	WAMSI Funding
3.1	**Biodiversity assessment and development of cost-effective monitoring protocols.** **Andrew Heyward, AIMS**	**1,755,000**
3.1.1	Deep water communities of Ningaloo Marine Park. Dr Andrew Heyward, AIMS Sub-projects 3.1.1a Deep water habitat types, including cross shelf bathymetry and sediment facies *Dr Andrew Heyward, AIMS* 3.1.1b Fish biodiversity associated with habitat types in sanctuary and adjacent zones *Dr Euan Harvey*, *University of Western Australia* 3.1.1c Species inventory database for Ningaloo deep waters *Dr Jane Fromont, Western Australian Museum*	985,000
3.1.2	Methods of monitoring the health of benthic communities at Ningaloo Reef. Dr Martial Depczynski, AIMS	370,000
3.1.3	Stock assessment of target invertebrates at Ningaloo reef. Dr Martial Depczynski, AIMS	150,000
3.1.4	Local and regional migratory patterns of whale sharks at Ningaloo Reef. Dr Mark Meekan, AIMS	100,000
3.1.5	Enabling dataset for physical oceanography of the Ningaloo Marine Park. Dr Richard Brinkman, AIMS	150,000
3.2	**Biodiversity assessment, ecosystem impacts of human usage and management strategy evaluation.** **Dr Russ Babcock, CSIRO**	**1,848,839**

[1] At the request of the WAMSI Board, $150,000 was provided for WAMSI central administration functions.

Ref No.	Project Title and Leader	WAMSI Funding
3.2.1	Diversity, abundance and habitat utilisation of sharks and rays. Dr John Stevens, CSIRO	100,000
3.2.2	Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation. Dr Russ Babcock, CSIRO Sub-projects 3.2.2a Broad scale fish surveys *Dr Russ Babcock, CSIRO* 3.2.2b Intertidal invertebrate species *Dr Bob Black, University of Western Australia* 3.2.2c Assessment of trophic cascade effects Dr *Glenn Hyndes, ECU* 3.2.2d Exploited lagoon invertebrates *Dr Russ Babcock, CSIRO* 3.2.2e acoustic tracking of fish *Dr Russ Babcock, CSIRO* 3.2.2f Finescale fish surveys *Ben Fitzpatrick, Dr Euan Harvey, University of Western Australia*	1,299,236
3.2.3	Management strategy evaluation Dr Rich Little, CSIRO	449,603
3.4	**Characterisation of geomorphology and surficial sediments.** **Prof Lindsay Collins, Curtin University of Technology**	**102,500**
3.5	**Characterisation and modelling of oceanographic processes.** **Prof Charitha Pattiaratchi, University of Western Australia**	**191,161**
3.6	**Science Coordination: Administration, communication and data management.** **Dr Chris Simpson, Department of Environment and Conservation**	**699,000**
3.7	**SRFME carryover projects – Jurien Bay** [2] **Dr Chris Simpson, DEC**	**N/A**
3.8	**Northwest Marine Research Inventory**[3] **Dr Chris Simpson, DEC**	**N/A**
3.9	**Post-graduate seed funding program** **Dr Chris Simpson, DEC**	**133,500**

[2] Research funded through the Strategic Research Fund for Marine Science, final administration undertaken through Node 3 with no additional funding.

[3] External funding was acquired for this project, WAMSI provided $20,000 in kind support along with the administration and coordination through Node 3.

Ref No.	Project Title and Leader	WAMSI Funding
3.9.1	Deepwater communities at NMP and ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation (see Projects 3.1.1 and 3.2.2) Ben Fitzpatrick - University of Western Australia (Supervisor – Dr Euan Harvey)	33,000
3.9.2	Characterisation of geomorphology and surficial sediments (see Project 3.4) Emily Twiggs- Curtin University of Technology (Supervisor – Prof Lindsay Collins)	22,500
3.9.3	The policy relevance of Choice Modelling: an application to Ningaloo Marine Park Abbie McCartney, University of Western Australia (Supervisor – Dr Michael Burton)	15,000
3.9.4	Quantifying impacts of the Leeuwin current on the ecology and biogeochemistry of the Ningaloo Reef Cecile Rouseaux, University of Western Australia (Supervisor (Dr Anya Waite)	18,000[4]
3.9.5	The population dynamics and habitat usage of the Indo-pacific humpback dolphin (*Sousa chinensis)* and bottlenose dolphin (*Tursiops truncatus)* found in the Ningaloo Marine Park Kristel Wenziker, Murdoch University (Supervisor – Dr Lars Bejder)	18,000[5]
3.9.6	The role of microbial communities in reef building corals along the Ningaloo Reef, WA Janja Ceh, Murdoch University	18,000
3.9.7	Hydrodynamic processes in the Ningaloo reef system over a range of space and time scales Soheila Taibi, University of Western Australia (Supervisor – Prof Chari Pattiaratchi)	15,000
3.9.8	The trophic ecology and habitat requirements of the manta ray (*Manta birostris*) in lagoonal systems of Ningaloo Reef, WA Frazer McGregor, Murdoch University (Supervisor – Dr Mike VanKeulen)	N/A[6]
3.9.9	Foraminifera of Ningaloo Marine Park[7] Justin Parker, Geoscience Australia (Supervisor – Dr David Haig)	5,000
3.10	**Assessment of coastal groundwater dynamics and linkages with the Ningaloo Reef** **Prof Lindsay Collins, Curtin University of Technology**	**120,000**

[4] Also, recipient of BHP Billiton Scholarship, supported through WAMSI.
[5] Project not completed.
[6] Recipient of BHP Billiton Scholarship, supported through WAMSI.
[7] The WAMSI funding was used to assist with the publication of the monograph 'Foraminifer form Ningaloo Reef'.

1 BACKGROUND

Ningaloo Reef is one of Australia's most spectacular marine environments and is recognised as a global biodiversity hotspot. It stretches over 300 km from North West Cape to Red Bluff on the northwest coast of Australia, providing habitat for at least 500 fish species, 250 coral species and 600 mollusc species, as well as a number of iconic large marine fauna such as whale sharks, humpback whales, dolphins, manta rays, marine turtles and dugong. This region has long been popular as a recreational site for fishing, snorkelling and other outdoor activities. Balancing conservation of this unique marine ecosystem with sustainable development of the region is a major challenge.

Ningaloo Marine Park (NMP) was established in 1987 to protect this iconic area. After an extensive review process, the boundaries to the marine park were extended to include the entire Ningaloo Reef in 2004 and a revised marine park management plan was released in 2005 which described the increase in area allocated to sanctuary zones along with recommended management activities and targets.

The review process highlighted deficiencies in the knowledge base needed to assess the adequacy and effectiveness of the marine park zoning and to address the potential impact of increased recreational use and tourism development on the marine park. The Western Australian Government recognised that a science-based understanding of NMP and adjacent regions, its biodiversity and ecosystem processes and how these interact with human and natural pressures would allow for better decisions to be made about its long-term management. Consequently, $5 M was allocated in 2005 for a research program to improve our scientific understanding and, ultimately management of human use of this iconic region. This investment was subsequently directed through the newly established Western Australian Marine Science Institution (WAMSI) in 2006 and became the basis for Node 3 – Managing and Conserving the Marine State: best practice management and underpinning science (Node 3) of WAMSI.

Through the process of developing the science plan and research program for Node 3, it became apparent that the initial investment by government would stimulate further research interest and investment in the region culminating in up to $36 million spent on research in NMP between 2005 and 2011. The two largest elements of this research were undertaken through Node 3 of WAMSI and through the CSIRO Wealth from Oceans National Research Flagship program: the Ningaloo Collaboration Cluster (the Cluster). These programs represent significant collaboration and co-investment from research partners and stakeholders including State government departments, National research bodies, Universities and industry. Together, Node 3 of WAMSI and the Cluster have worked collaboratively to ensure a fully coordinated and integrated research program that also recognises and incorporates external research where appropriate to deliver on key management outcomes and needs. Appendix 2 contains a list of all relevant research projects undertaken in NMP between 2005 and 2011, noting the contribution by WAMSI, the Cluster and other key participants.

The aim of this report is to capitalise on the very large investment that has been made in research at NMP over the last five years and ensure that the key findings are highlighted, along with their relevance and application to management on both a day to day and long-term level. However, as this report represents the culmination of the Node 3 Science Plan it is primarily focused on providing research summaries and data management details that specifically relate to the Node 3 research program. Information from the Cluster and other external research programs is provided as appropriate in relevant sections on implications for management, knowledge transfer and in the overall research database (Appendix 1). For further information on research outside the Node 3 program, see the Ningaloo Atlas for links to references and datasets (ningaloo-atlas.org.au) and the Ningaloo Research Program for Cluster final reports and project information (www.ningaloo.org.au).

This final summary report was developed in full consultation with the scientists involved in the Node 3 research program. Section 2 provides an overview of the development and implementation of the Node 3 Science Plan along with the complementary Cluster and additional external research. Section 3 highlights the outcomes from the Node 3 research, referring to additional research where appropriate. Sections 4 and 5 describe a number of significant implications for management resulting from the research program and the associated recommendations. These sections represent a synthesis of information across multiple projects and were developed using information from the Ningaloo Research Program Progress Report[8] and project final reports along with direct input from Project Leaders. The project summaries that comprise Section 6 were provided by individual Project Leaders. While these summaries have been edited for consistency and relevance to a non-technical audience, the conclusions and recommendations they contain are the responsibility of the principal author(s). Sections 7 through 10 address the knowledge transfer aspects for Node 3 including the process that was developed to enhance knowledge transfer along with the specific benefits and communication outputs that are now available. While the knowledge transfer process was applied to the full spectrum of research in NMP, benefits and communication outputs are only included for Node 3 projects in this report.

2 INTRODUCTION

Node 3 of WAMSI was led by the Department of Environment and Conservation (DEC). The Node's primary goal was to improve the scientific information base and tools for adaptive management of marine protected areas in Western Australia, particularly NMP, to ensure the sustainability of both ecological and social values. The Node 3 Science Plan addressed the following themes key to marine conservation through Marine Protected Area (MPA) management:

- bio-physical inventories and associated biodiversity assessments;
- characterisation and predictive capacity of the nature and levels of human usage;
- characterisation and modelling capacity of key ecological processes;
- development of cost-effective reef health indicators and monitoring protocols;
- characterisation and assessment of the ecosystem impacts of human usage, and an assessment of the effectiveness of the park's zoning for biodiversity conservation; and
- development and application of a multiple-use Management Strategy Evaluation framework to assess a range of development scenarios and to evaluate alternative management strategies to meet both conservation and socio-economic objectives.

NMP was selected as the geographic focus of the research program based on its iconic status as a marine biodiversity hot spot as well as on the recent review and revision of the NMP management Plan[9] along with the intense interest for coastal tourism development in the region. This culminated in a commitment by State Government of $5 million towards a research program that would provide better information to support not only the

[8] Waples, K and Hollander, E. 2008. Ningaloo Research Progress Report: Discovering Ningaloo- latest findings and their implications for management. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, WA.

[9] CALM. 2005. Management plan for the Ningaloo Marine Park and Muiron Islands Marine Management Area, 2005-2015, Management Plan No. 52. Department of Environment and Conservation, WA.

conservation, management and sustainable use of NMP but also the decision to nominate the Ningaloo Reef and Cape Range National Park for World Heritage listing.

A multi-disciplinary research program, which became the Node 3 Science Plan, was planned, based on the ecological and social values of NMP and the priority research needs identified in the NMP Management Plan, and developed in consultation with the science community and natural resource managers. The research program represented an integrated framework that would provide scientific information to support management of NMP.

At the same time CSIRO Wealth from Oceans National Research Flagship program also invested $2.5 million into a research program that would address the interplay between social and economic factors and biodiversity conservation in a multi-use marine park such as NMP. This research program, titled the Ningaloo Collaboration Cluster (the Cluster), was initiated in 2007 as a 3-year research program designed to integrate reef use, biodiversity and socio-economics through the development of a Management Strategy Evaluation modelling system. Together Node 3 and the Cluster created a complementary and integrated research program that would rely on clear communication and integration between both programs to maximise benefits.

The Node 3 Science Plan represents a multi-disciplinary collaborative research program involving at least 60 scientists from 8 research organisations and Universities working on the 25 major research projects. These projects have been structured into 11 main research areas with a number of subprojects contained within broader themes. The majority of the research undertaken through Node 3 addresses the physical and ecological background to NMP including baseline information on biodiversity, and improved understanding of ecological processes. However, there are additional elements on the effectiveness of current management strategies (e.g. sanctuary zones) relative to human use patterns and pressures.

Similarly, the Cluster comprises a multidisciplinary research effort of some 22 research projects undertaken by up to 40 scientists from 8 Universities and research organisations These projects aim to work towards delivering a system that can assess the impacts of various management decisions and development scenarios on the ecological and socio-economic status of NMP. This information can then be used to make informed management decisions about the development of the region and also to support robust and cost-effective monitoring protocols to determine the effectiveness of these decisions.

In addition to these large research program, other research projects were underway in NMP or were initiated during the tenure of WAMSI. Appendix 1 provides a full list of research projects undertaken at NMP between 2005 and 2011, highlighting the projects that comprise Node 3, the Cluster and additional research.

Both Node 3 and the Cluster have had as a key program goal, the integration of information and findings into a knowledge transfer and uptake process that would ensure the new knowledge gained from this science is used by the relevant management authorities. As such, there have been very strong linkages and communication both within and between these two research programs. A Ningaloo Research Coordinating Committee (NRCC) was formed in 2007 comprising representatives from Node 3, the Cluster and AIMS to ensure full integration and coordination of research programs and outcomes. This committee has been instrumental in bringing scientists, managers and the community together at shared forums and in preparing and presenting research findings to a broader audience through a range of media. Further, Node 3 has invested a significant amount of effort into developing and implementing a knowledge transfer and uptake framework to ensure that this new information is both relevant and used to inform and adapt the ongoing management of NMP (see Section 7). All in all the research initiated by Node 3 and expanded through these additional partners has culminated in a body of knowledge that is larger than the sum of its parts.

3 OUTCOMES

Node 3 was established to service WAMSI's strategic objectives to support priorities and programs of the Government's environment portfolio including the commitment to deliver an improved scientific knowledge base to support the development and implementation of biodiversity conservation policies and decision-making for the State's marine conservation programs. These objectives were achieved through the delivery of an integrated and multi-disciplinary science program aimed at improving the scientific underpinning of the management of NMP, an icon in the State's marine protected area system. Research on NMP over the past five years has produced at least a 10 fold increase in our understanding of this unique marine region along with the local and broader ecosystem processes that support it. This information is clearly of value to DEC, as the primary manager of NMP and will be used in its overall management through development and implementation of 'up-to-date' policy and planning activities as well as its day to day management of the marine park. Furthermore, the research has established baseline data on which to build a cost-effective and informative long-term monitoring program that will help assess the ongoing effectiveness of management strategies. While DEC have always been perceived as the main beneficiary of this research program, the information it has produced will be of broad interest to the community and of more specific interest and use to agencies tasked with Regional planning and development along the Gascoyne Coast and on and around the Exmouth Peninsula and greater Pilbara coast.

Overall we now have a far better understanding of the physical, biological and social characteristics of NMP. This includes background and baseline information on the physical structure of the reef along with its geological history and growth, a spatial understanding of benthic habitats and associated fauna communities, assessments of the diversity, abundance and distribution of many species that inhabit NMP from intertidal invertebrates through to fish and sharks as well as the social values embodied within the park. We have improved our knowledge of the ecological and physical processes that maintain and support the reef system and its vast array of biodiversity including oceanic currents and local hydrodynamics that bring nutrients to the reef in the form of phytoplankton as well as ecosystem interactions such as herbivory and trophic flow. Finally, we have examined some of the impacts on NMP and the effectiveness of the current management regime in minimising these impacts to maintain the system. All of these findings have been placed within the context of management so that we can plan ahead and use this new knowledge to support our current management activities, to make amendments where needed and to plan for the future to ensure the long-term conservation of NMP.

The research program undertaken through Node 3, and through its complementary partner program, the Cluster, encapsulates a very broad spectrum across a range of disciplines. Through the multi-disciplinary nature of the projects, we can begin to consider this information on a larger scale. This means having a better understanding of regional processes and issues as well as the capacity to consider particular management issues or concerns from a variety of perspectives that can be integrated into a better and more informed understanding. Such knowledge can be used to plan and support management strategies for improved conservation outcomes. Examples of cross-cutting issues informed by the array of research include the appropriateness and effectiveness of the current management framework, latitudinal gradients within NMP, pelagic coupling, establishment of long-term monitoring programs, climate change and identification of biodiversity surrogates. These issues are summarised, along with contributions from relevant projects in Section 6.

Below is a brief summary of the Node 3 expected outcomes detailing how each has been more than met by the breadth and diversity of knowledge created through this research program and the additional research interest and investment it has inspired. This summary is not comprehensive, but rather provides examples of achievements and their application. Reference is made in the following sections to specific Node 3 projects by reference number. For further detail on these research projects, findings and implications, refer to the individual project summaries in Section 6.

3.1 Improved capacity to plan and manage NMP and other marine parks and reserves

As noted above, a range of research projects from multiple disciplines provide background information to enhance the management of NMP, including support for earlier decisions regarding the management framework for NMP. Further, the research program has provided clear recommendations to improve the current management based on new knowledge of the biodiversity and physical environment. For example, understanding of the distribution of biodiversity and habitats in the deepwater of NMP has led to sound recommendations on improvements that can be made to current zoning scheme to achieve better conservation outcomes (Project 3.1.1).

This information is also highly relevant to the planning and management of future MPAs situated in similar environments and where relatively little is known (e.g. Montebello/Barrow Islands marine protected areas). In particular, several research streams have provided information that can be used to develop general guidelines for the early assessment and management of areas with little existing knowledge. For example, an understanding of coral reef fish home range and movement patterns can be used to inform the size and spacing of zoning schemes to best protect key fish species in other coral reef systems (Project 3.2.2). Similarly, relationships between underlying geomorphology and seabed communities have been identified that can be used as surrogates for biodiversity which can be used in MPA design in remote and poorly studied areas (Projects 3.4, 3.1.1).

3.2 Enhanced capacity to identify and manage current human impacts and predict risks

Several streams of research undertaken through Node 3 targeted not only quantifying and understanding human impacts on our marine assets but also improving our understanding of the underlying physical background that can be used to assess future risks from recreational activity (i.e. fishing), coastal development, climate change or catastrophic events such as oil spills. Together this information can be used to support and guide decisions about the current and long-term management of NMP and human use patterns.

For example, several studies have examined species that have traditionally been harvested in NMP to determine their current status, distribution and the relative effectiveness of current management strategies including zoning scheme and fishing regulations. Project 3.1.3 found that rock lobster were severely depleted during the commercial fishing era and are not recovering sufficiently, suggesting that some amendment to management is needed. A modelling exercise undertaken to examine the effect of recreational fishing on target species such as the spangled emperor has found that the current zoning scheme has improved conservation outcomes for this species, however there are additional changes that should be considered given the predicted increase in recreational activity at NMP, namely the exclusion of shoreline fishing in coastal sanctuary zones (Project 3.2.3).

Research into the physical background of the marine park, including geomorphology (3.4.1), groundwater system (Project 3.10) and hydrodynamics (Project 3.5.1) provide both information and recommendations related to coastal development of the region and how it may best be managed to minimise impacts on the biodiversity assets. This information is equally useful in managing risks to the public created by local currents based around the underlying geomorphology and oceanographic patterns.

Complementary contributions were made to this outcome through the Cluster which included dedicated research streams to identify and map current human use of NMP (Cluster 2) and to develop a model for making predications about visitor patterns and their impacts on NMP and the coastal environment (Cluster 3).

Information from this research can collectively be used to support decisions on management changes needed to ensure the sustainability of NMP biodiversity, to manage risks to the public, to guide coastal planning and infrastructure development within NMP and to establish an appropriate long-term monitoring program that will be suitable to detect changes in ecosystem health in a timely manner and link these to relevant impacts so that suitable mitigation strategies can be put in place where appropriate.

3.3 Enhanced capacity to determine value for money and assess management efficiency and effectiveness of Government- funded conservation and management programs

The Node 3 research program is a firm example of delivery of value for money from investment in science. The program was initiated with an investment of $5M by Government which has multiplied to $36 million spent on research in NMP through co-investment in WAMSI and other research programs between 2005 and 2011. Furthermore, Node 3 was designed with specific management objectives in mind and has more than achieved these by providing a wealth of information along with the necessary protocols and other useful tools that will be used in supporting, assessing and improving government management of the marine resources of NMP. The provision of baseline information, monitoring protocols and indicators will be used in conjunction with these tools to assess the effectiveness of management strategies, thus providing the opportunity to improve management efficiency and effectiveness in conservation programs at NMP.

For example, Project 3.2 was dedicated to determining the effectiveness of the management framework and strategies currently employed at NMP, namely the sanctuary zone scheme. This was assessed across a range of individual projects with specific focus on various biodiversity groups and ecosystem processes using a variety of tools and techniques. The research provided baseline data, monitoring protocols and key indicators for sharks, fish communities, intertidal invertebrates and rock lobster. It also confirmed that sanctuary zones are an effective tool to protect biodiversity within a marine park framework, however additional protective measures may be required for some taxa, dependent on the scale of human impact and local conditions.

The modelling exercise ELFSim (Project 3.2.3) took this one step further and developed a management strategy evaluation (MSE) model that could evaluate the effectiveness of various management strategies in the conservation of the key target fish species, spangled emperor. Similar findings were reported for sanctuary zones as noted above under a variety of possible scenarios. The model also provided some evidence of the value of both directed compliance activity and education programs.

Finally, a number of the research projects across disciplines and research partners have assessed research techniques and protocols for the assessment of various biodiversity groups with the view that cost–effective protocols were needed to establish long-term monitoring of marine values in the marine park. We now have sound advice, protocols, species lists/guides and reference sites to assess sharks, fish, intertidal invertebrates, rock lobster and benthic filter feeder communities throughout the park. Such information is a very valuable aid to the developing Western Australian Marine Monitoring Program (WAMMP) being established by DEC as it will set the stage for standard protocols to be developed and implemented and puts NMP ahead of the game in baseline data for future comparisons.

3.4 Improved community understanding and support for Government conservation and management programs

Communication has been one of the key goals of Node 3 throughout its tenure. This has included communication between scientists and managers, within the science community and with the general public. In particular, we have sought to engage with the community about the research underway to develop an awareness of the marine environment, the value we place upon it and what may be needed to ensure it is there for all to enjoy tomorrow. A joint communication strategy was developed between Node 3 and the Cluster and has included such activities as open public meetings and interviews with local radio and media, publication, distribution of a series of project profiles highlighting individual research projects and hosting of the third Ningaloo Research Symposium in Exmouth. Additionally, the Cluster has engaged in extensive community and stakeholder consultation through their research program dealing with both visitor destination and MSE models. These meetings and presentations have played a key role in communicating results and information to marine park managers as well as to the broader public to improve the acceptance and support for management activities in NMP.

The research itself has also produced a vast array of information and products on the marine biodiversity in NMP and pressures upon them that is broadly suitable for the development of education programs and campaigns to foster community understanding and support for marine conservation and management. For example, the geomorphology study provides interesting diagrams that tell the history of Exmouth Peninsula across the ages, ending in the recent growth of the Ningaloo Reef (Project 3.4). The study on fish movement patterns using acoustic tracking has wide community appeal as it tells the stories of individual fish and their daily movements within the park (Project 3.2.2e). Community education and fostered understanding is a long-term process and one that is firmly entrenched in DEC core responsibility. DEC's activities and initiatives in this regard are now more fully informed based on the research and associated products and outputs (e.g. video, photos, project profiles).

In addition to the activities led by DEC, the new science now available on NMP will be made accessible through a dedicated website hosted by AIMS (Ningaloo Atlas). This website is supported by Node 3 and DEC and will be useful in ensuring the science reaches the managers of NMP and the local and wider community in an understandable and accessible format long into the future.

3.5 Improved links and collaboration between State and Commonwealth agencies and research bodies, universities, industry and NGO's

Node 3 of WAMSI has been largely a collaborative effort that has engaged all of the major Universities in WA along with national research bodies and government departments that have a role in coastal and marine management. All in all there have been up to 60 scientists working on Node 3 projects alone from 8 institutions. Many of the projects comprised both multidisciplinary and cross-institution teams. For example, the deep water biodiversity project led by AIMS included major components contributed by the Western Australia Museum, Curtin University and University of Western Australia. Similarly, the project on developing methods to monitor coral reef community health, also led by AIMS, included research participants from DEC. The involvement of scientists from various institutions has allowed for a real cross fertilisation of ideas and expertise and has engendered further interest in partnerships for future research projects.

In addition to the Node 3 research, this WAMSI research program has been a catalyst for other research conducted at NMP, most notably the CSIRO Wealth from Oceans National Research Flagship program the Ningaloo Collaboration Cluster. Both WAMSI and the Cluster worked collaboratively to bring the research programs together to ensure they were complementary and also that they provided a forum to engage researchers with an interest in NMP to discuss their findings and ideas within the context of the Region. Three open symposia have been held since 2007 along with a final synthesis workshop to bring the science together into a cohesive picture of the Region. The research at NMP is certainly an example of a case where the whole is larger than the sum of the individual parts. This has only been possible through the open collaboration between researchers and projects and relationships forged to advance science in the region.

The ongoing impacts of this effort are evident in the future plans for ongoing collaborative work not only at NMP, but other areas of WA, between DEC, AIMS, CSIRO and the Universities in WA including joint proposals submitted for funding through the ARC program, the Net Conservation Benefits program and Caring for Country. Improved linkages and collaboration has been most clearly demonstrated through the development of the Kimberley Marine Research Program currently being developed through WAMSI II. Due to existing relationships, partnerships and shared understandings even across disciplines will no doubt lead to a rapid and efficient project planning process.

3.6 Enhanced capacity and skill base for delivering marine science in Western Australia (including student training)

Node 3 has been instrumental in increasing the capacity to deliver marine science in WA as evidenced by the number of students who have participated in the research program in the advancement of their studies. The Node 3 research program directly supported 9 students through research grants and scholarships. An additional 13 students participated in the research at NMP as part of their studies with a further 10 students using information or resources from the Node 3 research program to further their studies. Node 3 also supported 3 post doctoral positions in WA as part of research projects bringing in new scientists from interstate and overseas.

In addition to the direct funding and support provided by WAMSI, the research program also acted as a catalyst to generate increased interest in research at NMP. This is clearly evidenced by the growing number of students actively involved in research over the timeframe of WAMSI. Significant effort was invested in recognising student achievements and the broad array of science being produced by our developing scientists through the joint hosting of a Ningaloo Student Science Day in 2009 by Node 3 and the Cluster. Twenty one students participated in the first Student Day followed by more than 30 in

2010. Given the vast increase in the number of students engaged in research at NMP by the end of WAMSI (9 to more than 30), this was deemed to be a successful endeavour and one that will continue to reap benefits into the future.

3.7 Improved capacity to plan and manage recreation, tourism and fishing.

Both the Node 3 research program and the Cluster have engaged in research on human activities in NMP and the impacts on biodiversity either currently apparent or predicted under future scenarios. Together these projects have vastly improved our understanding of human use and aspirations for NMP as well as the consequences for natural populations of biodiversity. This information will provide for sound and science-based decisions on the management of recreational and commercial activities in NMP such as the need for additional or amended regulatory measures particularly in conjunction with planning for future infrastructure.

Some of these studies have examined the interaction between tourism and biodiversity with a focus on megafauna such as whale sharks (Project 3.1.4) and large rays (Project 3.2.1). These studies have provided a better understanding of the species of interest and their behavioural ecology. Such information is very valuable in planning and implementing management programs for sustainable wildlife viewing and will be used to manage activities for both conservation and socio-economic outcomes.

Other studies have looked at species targeted by fishing to determine the status of current populations and the effectiveness of the current management framework (e.g. rock lobster – Projects 3.2.2 and 3.1.3 and fish – Projects 3.2.2, 3.2.3). Finally, an improved understanding of water circulation through the lagoons and the currents around NMP (Project 3.5) can be used in risk mitigation planning to select and promote the most suitable sites for visitor uses such as swimming, snorkelling and dive trails.

Research through the Cluster has added to this information base by assessing patterns of human use and identifying factors that concentrate these patterns of use at specific sites along the reef (i.e. availability of boating facilities, etc). This information combined with that of the predicted visitor patterns under various scenarios will be used to inform reviews of the management framework to better achieve conservation objectives, in particular in conjunction with expected increases in the level of tourism activity, and thus pressure, on NMP biodiversity.

3.8 Improved regional understanding, context and relative conservation significance of the key marine biodiversity assets in NMP

The key marine biodiversity assets, as detailed in the NMP Management Plan, have been thoroughly assessed through this research program. We now have a sound knowledge base of diversity, abundance and distribution of a range of taxa throughout NMP including sharks and rays, fish and intertidal invertebrates. Most significantly, we now have a description and understanding of the benthic habitats and their associated biodiversity for the deep waters, seawards of the reef crest, an area that until now has remained largely unknown. This information together demonstrates the clear significance of NMP as a biodiversity hotspot, supporting its recognition both as a WA icon and a World Heritage site. Further, we have a better understanding of regional dynamics at play in NMP given the tropical influences from the north and temperate influences from the south coupled with the geological history of reef and coastal formation that have led to very different species communities across the marine park. This information is significant as it has a strong influence on how we view NMP as a whole and how we best plan and manage for the conservation of the wealth of biodiversity it contains.

For example, the deepwater benthic biodiversity surveys (Project 3.1.1) have identified rich benthic communities populated by many new species, some of which are not currently represented within sanctuary zones and thus provided the highest level of protection in the park. The regional and global significance of NMP has been further demonstrated through the selection of NMP as a site for the global Census of Marine Life. This study has focussed on invertebrate fauna at NMP and has identified hundreds of new species across a range of taxa.

This information will be used in the next review of the NMP Management Plan to inform decisions made to alter the zoning scheme so that it is both comprehensive and representative of the biodiversity in NMP. Further, all biodiversity surveys (fish (Project 3.2.2a,e), sharks (Project 3.2.1), invertebrates (Project 3.2.2b), benthic communities (Project 3.1.1d)) have identified strong regional differences in biodiversity across NMP, highlighting that conservation and management will need to be tailored to ensure conservation objectives can be met at this regional level as well as across the Park.

3.9 Enhanced capacity to understand, adapt and mitigate climate change impacts

This research program has provided a much better understanding of the biodiversity of NMP and the oceanic processes that support it that will be influenced by climate change. However, further research is needed to examine the resilience of the coral reef and its communities as well as the means of monitoring these changes. This information will allow us to best manage the marine park and the region so that impacts from climate change can be minimised, in particular when occurring in conjunction with other development impacts.

Research on geomorphology, specifically morphological history of the reef (Project 3.4), has delivered a sound understanding of the historical backdrop to the development of the coral reefs of NMP including its response and growth rate when faced with climactic disturbances and change. Project 3.10 has added to this information by providing further insight into the coastal plain and groundwater system. This information highlights vulnerable sites along the Ningaloo coast that could be subject to heavy impacts if coastal development occurs in conjunction with predicted climate change impacts such as increased storm activity and sea level rise. While this research has begun to investigate the potential impacts of climate change in this temperate/tropical overlap area, it is only a starting point. Node 3 has provided baseline information and implemented several ongoing projects on the impacts of climate change on coral reef communities which serve as a basis from which to further explore coral reef response and resilience to climate change.

Project 3.5, in conjunction with research from Node 2 of WAMSI has assessed and modelled the current system that feeds and supports Ningaloo, noting the presence of a periodic summer upwelling (i.e. cooling) system that has provided some protection from warmer waters that have had such a large impact in other tropical environments. The model describes the circumstances where this protection is and is not present, an important factor to recognise given the coral bleaching event of 2011.

3.10 Increased capacity to respond to and mitigate the impacts of oil spills

This outcome has been achieved through two research areas that have produced information, maps and models that can be used in the response and management of events such as chemical or oil spills. First, the Node 3 research program and the Cluster have delivered an improved understanding of the biodiversity within NMP and its distribution throughout the park, including accurate habitat maps that can be used to identify significant and potentially vulnerable biodiversity (Projects 3.1.1, 3.2.2, 3.4). Second, Project 3.5 has specifically examined and modelled water circulation and hydrodynamics across the reef and inside the lagoon system of NMP. Together this information can be used to identify sensitive sites of high biodiversity value and/or vulnerable areas that may be more exposed to contamination in the event of a chemical spill. Further the circulation model can be used to model and predict where contaminated water will move through the park and the duration of its presence. The maps and models will both be valuable tools in the event of an oil spill to plan and manage so that impacts on biodiversity are minimised.

3.11 Development of pathways and protocols between researchers and end-users to enhance knowledge transfer and uptake

In addition to vastly improving our understanding of the marine environment and biodiversity of NMP, the Node 3 Science Plan has produced a number of key products that will be of ongoing use to natural resource managers. It is of critical importance that end-users not only are aware of these sources of information and tools, but have a need and ability to use them. As such, knowledge transfer and uptake has been a key goal of Node 3. Science delivery is only one step in this process and a clear framework and plan is required to interpret and promote science findings so that they are recognised and integrated into management practices and decisions.

Node 3 has invested significant effort into the development of an operational framework and process for knowledge transfer and uptake that begins with science planning and culminates in the ongoing support for interaction between managers and policy makers and scientists (described in Section 7). In this regard Node 3 has led a directed research program focussed on management needs which has in turn produced science reports that articulate the management application of science findings. Further activities have led to improved interaction and dialogue between scientists and operational managers as well as policy makers which will ensure findings are translated into action when required.

Finally, along with the vast amount of information and its careful interpretation to maximise value to management, the Node 3 research program has set into place clear pathways and processes to ensure that this information is delivered to end users in a useful format and will be ready for uptake. This process recognises that knowledge transfer is a gradual systematic process that can occur over a decade between research completion and actual implementation of management outcomes and has sought to include the best means of ensuring the longevity of the information and its implications through the development of appropriate and useful data and communication products as well as clear and accessible data management led by WAMSI.

Summary

All in all the body of research that comprises Node 3 has far exceeded the original expectations and commitments made through WAMSI. The many scientists who have worked at NMP over the past 5 years have produced a large amount of data and information on this important region, much of which has yet to be assessed for its full implications. While there are many more research and management questions that can be further explored with the existing information, we now have a sound basis on which to base management decisions and from which to plan future research.

4 KEY RESEARCH FINDINGS AND IMPLICATIONS FOR MANAGEMENT

This section provides an overall summary of the Key Findings that have come about through the individual research projects in Node 3 and their interaction to address cross-cutting issues. For more detail on specific projects and findings see Section 6.

As noted above, the Node 3 research program has vastly increased not only our understanding of the NMP ecosystems and the physical and ecological processes that support them, but also the level of impact from human pressures in the marine park and consequent effectiveness of management strategies.

While NMP is considered, and has been found to be, a relatively undisturbed coral reef environment with good water quality and a healthy coral reef system, there are still a number of anthropogenic pressures upon the reef and its biodiversity. The largest impacts come from recreational fishing and development for increased tourism in the area. Overall the current management regime has been demonstrated to be reasonably effective with no evidence of trophic cascade impacts and reasonable protection for the various biodiversity groups, including target species. However, there are a few areas where the management framework is not providing adequate protection, including adequate representation of benthic communities within the current zoning scheme, a lack of recovery of rock lobster from the intense depletion during commercial fishing and human impacts on coastal vegetation. There is further evidence that some target species (fish and octopus), due to their life history characteristics and behaviour may remain vulnerable to human pressures given the current management strategies. Recommendations have been made across a range of projects that should be considered in future reviews of the NMP Management Plan to ensure best practice conservation management.

4.1 Regional and global significance

The physical values of the region are best described through research on the geomorphologic history of the region by Project 3.4. This project led to descriptions of the ancient history of the reef and the adjacent land formations and the window that this affords us to view the response of coral reefs to climate change. Project 3.10 broadened the picture by also examining the underlying karst system that links the groundwater system of Exmouth Peninsula with the Ningaloo Reef and the wider oceanic system beyond. Such linkages are crucial for the evolution and support of the unique ecosystems and biodiversity that inhabit NMP.

The significance of the biodiversity in NMP has also been clearly demonstrated through a number of these recent research projects. Most notably, research on deep water benthic communities has identified large areas of sponge garden as well as a huge number of new species of sponges as well as other benthic invertebrates (Project 3.1.1d, Schonberg and Fromont 2011) and the Census of Marine Life. Through these studies NMP has been demonstrated to be a hot spot for benthic biodiversity, much of it unique to the region. Similarly NMP has stood out as a hot spot for other biodiversity as well relative to other reef systems. For example, shark and ray diversity is equal to that of the Great Barrier Reef despite NMP being less than one third the size and includes at least one new species of ray possibly endemic to the marine park (Project 3.2.1). Studies on intertidal invertebrates have also found very high diversity with new species and range extensions to many known species recognised (Projects 3.1.1c, 3.2.2b).

The physical and ecological processes of NMP were also investigated and found to represent the key driving forces that, combined support this broad range of biodiversity. Ningaloo Reef is uniquely situated on a west coast, in an area near the continental shelf that is exposed to oceanic processes such as the Leeuwin Current and deep water upwelling. Seasonal changes in weather patterns and currents contribute to the nutrient rich waters which not only feed the reef (Project 3.5.2), but also attract species such as the iconic whale shark (Project 3.1.4).

All in all, the marine research undertaken at NMP over the past five years adds a huge amount of support and evidence that Ningaloo Reef is well deserving of its World Heritage listing status. It is a unique and biologically rich environment.

4.2 Latitudinal gradients

The physical context of NMP has led to a unique distribution of the biodiversity which has important implications for the management of the region. As expected, biodiversity and species assemblages vary with water depth and habitat (i.e. the lagoon system contains different species assemblages to the reef slope, reef crest and deeper waters seawards of the reef). However, long shore differences have also been documented, providing strong evidence for a latitudinal gradient within NMP. These differences are influenced by NMP's exposure to both tropical and temperate oceanographic influences as well as topography and geomorphology of the region. Combined, these factors have led to distinct bioregionalisation of NMP with very different species assemblages in the northern and southern ends of NMP. The central region (i.e. Point Cloates) not only acts as a dividing point, but also contains its own unique biodiversity and assemblages due to the complex geomorphology and habitats created by a series of benthic pinnacles and ridges there. For example, while there are five rock lobster species found in NMP, (1 temperate and 4 tropical), the temperate species is more common in the southern end of the marine park whereas in the north the four tropical species are more common. Point Cloates stands out as a transition area from tropical to sub-tropical influence, representing a unique area in its own right (Projects 3.2.2d, 3.1.3). Similar north to south patterns were reported for fish species (Projects 3.2.2, 3.1.1, 3.2.2f, 3.2.2c). Research on deepwater benthic biodiversity found very rich patches of biodiversity throughout the park with enough variation between areas to make each region significant in its own right and deserving of specific conservation effort (Project 3.1.1).

Ultimately, this variation in species distribution throughout the park has very important implications for the management of NMP and, in particular, the management of biodiversity values. Management frameworks will need to take into account the variation in species distribution throughout the marine park and incorporate a zoning plan that will adequately protect the different biodiversity assemblages throughout the park. Similarly, management should recognise that temperate and tropical species may be at the end point of their range and that NMP may represent sub-optimal habitat for a number of species present there. Thus some species, in particular those of commercial or recreational interest, may require special protection to ensure that the populations recover and remain sustainable (e.g. rock lobster). Finally, this observed latitudinal gradient bears further watching and sets the stage for monitoring and research on the impacts of climate change and consequent changes in species' distribution based on changes to the physical environment.

4.3 Is the zoning scheme for NMP appropriate?

NMP is a multiple use MPA, comprising several types of management zoning intended to achieve a wide range of goals, but primarily to preserve biodiversity and ecological values within the park. Within this zoning scheme sanctuary zones are used to protect representative areas of important habitat, ecological systems and processes. These are areas in which no extractive activities (e.g. fishing) are permitted to occur. The zoning scheme for NMP was initially established in 1991, but was reviewed in 2004 and expanded because it did not provide representative protection throughout the park (namely deep water and reef front habitat). The revised zoning scheme was based on the best available information at the time and was subject to some criticism for its lack of scientific evidence. One major goal of this research program was to remove this uncertainty and provide clear evidence that could be used to support or improve the zoning scheme to meet conservation and social objectives.

The research that has been undertaken over the past 5 years has greatly extended our knowledge base about NMP and in particular the distribution of biodiversity within its boundaries. Overall the findings generally confirm that the rezoning of the park has achieved a more comprehensive representation of ecological processes and biodiversity throughout NMP. For example the latitudinal differences in species assemblages detected across a range of biodiversity confirm the importance of sanctuary zones in all regions of NMP. The extension of sanctuary zones into deeper waters of the NMP was supported by the identified differences in fish assemblages at various depths, along with the age related use of these areas (Project 3.1.1b) and their placement has aligned with many of the rich and unique benthic communities present seawards of the reef. Biodiversity surveys have confirmed that the expansion of sanctuary zones to include habitats and regions in the north and south of the park has led to the inclusion of a broader suite of fish assemblages, lobster populations and intertidal invertebrates. Similarly, the expanded inclusion of reef slope habitat has resulted in a much more representative system of sanctuary zones as reef slope fish and invertebrate assemblages and ecological processes are distinct from those on reef flat and lagoon areas. Finally, the size of current sanctuary zones were generally found to be appropriate given new information on fish movement patterns and habitat use across the reef (Project 3.2.2e).

However, several studies have also provided evidence that further improvements could be made to the zoning scheme in NMP and this information should used to inform future revisions of the park management framework to more fully represent NMP's biodiversity. There are still areas within NMP where adequate protection may not be provided to the marine biodiversity and key fish species vulnerable to exploitation from recreational fishing. For example, sanctuary zones in the northern area of NMP are relatively small (average 5.56 km^2) and typically do not include much reef slope habitat. Project 3.2.2e has shown that many predatory fish species (typically those prized by recreational fishers) have foraging ranges and movement patterns larger than these sanctuary zones and have a high concentration in reef slope habitat. To provide adequate protection for these species and to meet key management targets regarding fish biodiversity and abundance, sanctuary zones in the northern area of NMP should be larger and should incorporate more reef slope habitat.

Research on deep water habitats and communities has found extensive sponge and soft coral gardens that are not adequately represented within the current zoning scheme. Minor amendments would be required to extend existing zones in the southern and northern sections of NMP as proposed by Project 3.1.1. In addition, there is evidence that sponge garden communities become increasingly abundant and diverse at the outer boundary of State waters and into Commonwealth waters at the northern end of NMP that are not within the Commonwealth marine park boundaries. Some consideration may need to be given to the conservation management strategies suitable between Commonwealth and Western Australia jurisdictions to adequately protect these important benthic habitats.

Even though sand and mangrove habitat is limited in NMP, it has the highest sighting rate for sharks and rays (Project 3.2.1). Thus the representation of this habitat type should be considered when reviewing the management framework.

Finally, along shelf and cross-shelf differences in species assemblages mean that sanctuary zones are needed along the length and breadth of NMP and should incorporate suitable and representative habitat (i.e. deep water, reef slope, reef flat, channels, lagoon) within each region to adequately represent fish biodiversity.

Currently 34% of NMP is protected by sanctuary zones, however not all habitats are represented equally. In particular, even though substantial increases to their representation were made in 2005, only 23 and 24% of reef slope and deep water community habitat are currently protected by sanctuary zones respectively (Beckley and Lombard 2011). These habitats are mainly under-represented in both the northern and southern ends of NMP. Sanctuary zones in the northern section of NMP include the lowest representation of these habitats of any region in the park, yet they are the most heavily fished and likely to be in greatest need of protection now and in the future (Project 3.2.2). The next review of the NMP Management Plan should take these deficiencies into account based on the new information on the distribution of biodiversity throughout the marine park highlighting regional differences in species assemblages across a range of taxa.

4.4 Are sanctuary zones effective?

One project stream comprising 8 projects specifically addressed the effectiveness of zoning for biodiversity conservation in NMP. It assessed multiple aspects of coral reef ecosystems at Ningaloo relevant to current and future management of the marine park. In general this research has demonstrated that the zoning implemented in 1991 has achieve positive outcomes in biodiversity protection and that the rezoning implemented in 2005 is likely to achieve further conservation outcomes. However it also noted the need for ongoing evaluation of management effectiveness as there are indications from a range of sources that there may be aspects of park configuration requiring further management action to realise park management goals.

There is now substantial evidence that sanctuary zones are protecting populations of targeted species. This was demonstrated through the fish survey research (Project 3.2.2a) which found higher biomass of target species such as spangled emperor and cod inside sanctuary zones relative to outside as well as research on shark distribution (3.2.1). Additionally, studies on trophic relationships at NMP found no evidence of trophic cascade effects typical of intense fishing in other tropical reef systems. So far the evidence for NMP suggests the reef ecosystem and communities are relatively stable, displaying high diversity and abundances.

However these studies have also provided evidence that recreational fishing is having a measureable affect on targeted species and populations. It is a matter of determining what level of affect is acceptable and ensuring appropriate management strategies can be put in place so that conservation targets are met. For example, spangled emperor have notably declined since 1991 across NMP, with this decline somewhat buffered inside sanctuary zones relative to outside. Similarly, the abundance of rock lobster have severely declined since the commercial fishing era that ended in the 1980s. Sanctuary zones alone may not be adequate to the recovery of these populations or even stopping their decline. Alternative strategies are discussed in the section below (Fishing regulations).

4.5 Compliance

Assessing the effectiveness of sanctuary zones relies heavily on the assumed compliance with the management framework by users of the marine park. Project 3.2.2 undertook such an investigation using relatively short-term, comparative biodiversity assessments of fished and unfished areas of NMP. It is important to note that there are other factors that influence the interpretation of these results. For example, differences in biodiversity attributes between fished and unfished areas can be interpreted as evidence of the effectiveness of sanctuary zones and be the result of differences in historical and current fishing pressure, based on the assumption that compliance programs have been and are leading to significantly lower fishing pressure inside sanctuary zones. However, where no differences are found this can be interpreted as that either the sanctuary zones are ineffective, as designed, for biodiversity conservation, the impacts of fishing are insignificant compared with other factors influencing the biodiversity or that the sanctuary zone compliance programs are ineffective (i.e. fishing pressure was not significantly reduced in the sanctuary zones). Thus, forming a conclusion (either way) is dependent on the effectiveness of compliance programs.

While the level of compliance exhibited in NMP was not a specific research area within Node 3 or the Cluster, information has been provided of significant non-compliance through the project on human use patterns in NMP (Cluster 2) as well as through the observations of individual scientists during field activities. Cluster Project 2 reported 12-20% non-compliance with the zoning scheme by fishing vessels and a number of Node 3 scientists similarly reported regularly sighting non-compliance activity in sanctuary zones during their field observations. This does have some implications for the research findings on zone effectiveness, and certainly indicates that investment not only in improving compliance, but also in providing a better understanding of compliance effectiveness with the current management regime is warranted to improve future assessments of NMP management programs.

4.6 Fishing Regulations

Several studies have examined the impact of human activity on the biodiversity of NMP, in particular that of recreational fishing. As noted above, while the current management framework which includes a zoning scheme and general fishing regulations have been reasonably successful in maintaining the biodiversity of NMP, the impacts of fishing are measureable. For some species a gradient or a marked difference is apparent in populations that are or have been exposed to the highest levels of fishing.

Western rock lobster are a case in point. This species was widely exploited in the 1960s under a commercial fishery in the southern area of NMP that ceased to operate in the 1980’s due in part to the decline in lobster numbers. Currently rock lobster numbers remain low, and very patchy in distribution. As the western rock lobster is at the northern extreme of its range there is the added pressure of climate change on this temperate species. Thus consideration should be given to additional management strategies such as a cessation or moratorium of fishing for western rock lobster within NMP to enable this population to recover.

There is also evidence from several projects of the impact of fishing on key target species across NMP given the new information on species distribution and habitat use. In particular, it was found that species such as the spangled emperor are vulnerable to shore based fishing as they exhibit a high use of shore line habitat in lagoons along NMP. Additionally, species that aggregate at specific spawning sites may be more vulnerable at these times and places as they become more broadly known among the fishing community. The modelling exercise undertaken through Project 3.2.3 clearly identified that fishing pressure can have a measurable impact on key fish species and that, given various scenarios for future tourism growth and recreational activity, sanctuary zones alone might not be a sufficient management tool to achieve conservation objectives. Additional measures that bear considering include amended bag limits, removing shore-based fishing from within sanctuary zones and ensuring aggregation sites (when identified) are protected.

Finally, project 3.2.2c identified herbivory as a key ecological process responsible for maintaining the resilience of biodiversity and systems at NMP. While currently herbivorous fish are not subject to fishing pressure at NMP, they are in other coral reef systems, with consequent impacts on the overall system. It would be wise to pre-emptively regulate take of herbivorous species at a time when there is little appeal in taking them.

4.7 Western Australian Marine Monitoring Program (WAMMP)

DEC is in the process of developing and implementing a state-wide MPA and threatened/marine fauna, long-term monitoring program. The main focus of WAMMP will be on key marine assets identified in each of the MPAs in WA as well as large marine fauna that occur throughout State waters. As a first step in this process effort has been directed at reviewing the relevant marine assets along with best practice techniques for their assessment. The Node 3 research program provides significant information into WAMMP not only to support and establish the developing monitoring program for NMP, but also to inform monitoring practices and protocols in other tropical MPAs in WA.

Some studies have had a key focus on the development of cost-effective monitoring protocols, such as Project 3.1.3 which has assessed, designed and trialled monitoring techniques for both coral and fish recruitment to assess reef health. Other projects have undertaken biodiversity assessments that have produced baseline information as well as recommendations on best and most cost-effective techniques for field assessments of taxa such as elasmobranchs, intertidal invertebrates, fish, rock lobster and benthic filter feeder communities. Additional products have been produced from some projects that will be useful in ongoing research and monitoring activities such as field guides for juvenile fish and intertidal invertebrates.

Finally, research that has improved our understanding of the physical and social characteristics of Ningaloo Reef, and most importantly, mapped geomorphological features, sediments, habitats and human use which will be equally useful in research and monitoring program design as an information source from which to select reference sites.

4.8 Cross-shelf links from lagoon to deep water – pelagic coupling

Not only were latitudinal differences in biodiversity patterns examined for NMP, but also the relationship between fauna assemblages and processes from the lagoon to the deep water and open ocean beyond. Significant evidence was found for strong linkages between the deep water, oceanic processes and the functional health of both the reef and lagoons. For example, Project 3.1.1 found that fish species use different parts of the environment across the continental shelf at different times in their life history, identifying certain habitat as nursery, juvenile and adult and linking the entire system. Further, the biological oceanography project found that the reef is fed predominately by seasonal plankton blooms in the Leeuwin Current and is thus dependent on these oceanic processes for nutrition and overall health. Evidence of links between the groundwater system (3.10) and deep water habitats through benthic features found at 80-100m depth added a physical element to the connection between the coast, lagoon and coral reef habitat and the ocean.

4.9 Climate Change

Many studies describe the physical, social, biological and ecological information that provide background to investigate how NMP may experience climate change. Some projects have also explicitly dealt with climate change associated threats and examined implications for coastal and marine environments at NMP. This information highlights sensitive areas and issues and should be included in future consideration of coastal development and marine park infrastructure. It should be noted though that the research undertaken through Node 3 is just a beginning in understanding climate change and the implications for NMP, and should be viewed as providing a basis and some direction for further research on specific impacts, forecasting and adaptations. Some particularly relevant studies are outlined below.

Research on reef growth history and geomorphology has described historical responses of the Ningaloo reef system to climate change including sea level rise and fall (Project 3.4). This information provides some context for understanding spatial variation in rates of reef accretion and highlights the areas that have traditionally been vulnerable to these changes in sea level (e.g. reef on the Exmouth Gulf side such as Bundegi).

Preliminary investigation of the groundwater system noted that this system will become vulnerable to changes in climate (Project 3.10). In particular changes to rainfall and severe storm activity alters rates of coastal erosion, flow of ground water and flooding. Vulnerable sites should be considered in future regional planning and additional protective measures considered for aspects of the groundwater system that are vulnerable to human and natural activity.

Many biodiversity studies across a range of taxa confirmed that NMP represents the northern extreme in range for a number of temperate species (Projects 3.1.1, 3.1.3, 3.2). Thus, NMP is not necessarily optimal habitat for these species and increases in water temperature may push some of them out of this range, leading to changes in biodiversity and species assemblages through the park. Understanding how changes in climate drive temporal shifts in species distributions allows us to separate these factors from other potential drivers of distribution patterns and identify when management intervention is appropriate. Continued development of species tolerance levels to climate change stressors physiological will further this cause.

While oceanographic studies on hydrodynamic models and currents has observed that NMP is afforded some protection from increase in water temperature by the seasonal upwelling that brings cooler water to the reef in the hottest months (Project 3.5.1), events such as the coral bleaching in the summer of 2011 are demonstrating that there are other factors at play. The implications of climate change on larger oceanic processes has potential to have indirect impacts on NMP. For example, changes in offshore currents like the Leeuwin Current, may have serious implications for the health of NMP if these effects include disrupting the production and supply of phytoplankton to the reef (Project 3.5.2) or connectivity. Similarly, ocean acidification may have long-term implications for phytoplankton communities and changes to ocean biogeochemistry could also interrupt phytoplankton delivery to Ningaloo reef.

These factors point to a need for increased awareness of the possible implications of climate change, their consideration in future planning, particularly for coastal development and visitor infrastructure, and the need for ongoing research and monitoring of biodiversity response to climate change and reef health.

5 RECOMMENDATIONS

- Ensure that the results of this research program are broadly disseminated through resource management agencies and made available and accessible into perpetuity.
- Consider employment of a 'knowledge broker' within the Science Division of DEC to support the integration of knowledge from Node 3 research program into policy and management action through implementation of the priority actions identified in the knowledge transfer framework (e.g. acquisition of data in appropriate formats, development of management guidelines, creation of GIS referenced maps).
- Review the NMP zoning scheme at the next review of the NMP Management Plan in light of the new information provided on the distribution of biodiversity in NMP and the current under-representation of some habitats in the zoning scheme (e.g. northern NMP, reef slope and deep water communities). This should include:
    - Recognition of the both latitudinal and cross-shelf variation in biodiversity and community assemblages across taxa, leading to a need for protection of representative habitats throughout the marine park.
    - Recognition of the significant benthic biodiversity in the benthic environment of the deep water offshore of Ningaloo Reef (i.e. sponge gardens). Representative communities of these sites are not adequately protected in the current scheme in the northern and southern areas of NMP as well as in adjacent commonwealth waters. Additional protection through extension of sanctuary zones or other measures that will protect benthic habitats is warranted to address these deficiencies.
    - Consideration of the size of sanctuary zones in the northern region of the marine park relative to the size deemed adequate to support viable populations of key biodiversity assets.
- Consider additional management strategies to proactively maintain ecosystem resilience and biodiversity in NMP over the long-term in the face of increased recreational activity and climate change. This could include banning the take of herbivorous fish species (currently non-target species of low recreational value), amending bag limits for target fish species and ensuring all known spawning sites are protected within sanctuary zones.
- Consider removing shore-based fishing zones within sanctuary zones of NMP so that species such as spangled emperor will be more adequately protected.
- Initiate more stringent management of the take of rock lobster within NMP to promote the recovery of the western rock lobster. This could include a moratorium on the take of western rock lobster and reducing the bag limit of tropical lobster species.
- Review all coastal development applications with a view to their relative impact on the groundwater system (e.g. removing water or possible overflow into the system). To enhance this capacity, proponents of coastal development should be required to investigate and map the groundwater system at the site of interest and adjacent areas.
- Use the breadth of new information available on NMP, along with the visual resources produced (photos, video, maps), to develop education programs and resources that will improve community knowledge and understanding of the unique biodiversity within NMP. Specific topics for education tools/programs could include:
    - the rich and unique biota present in deep water benthic habitats;
    - whale shark behaviour and use of NMP, emphasising risks of human impacts such as boat strike;

    - the presence and protective requirements of important species within NMP (i.e. endemic and/or specially protected species such as the green sawtooth shark) as well as the correct handling and release procedures for sharks; and
    - the importance of paleohistory and the development of physical features that underlie Ningaloo Reef (including the karst system) to the reef's health and potential impacts of human use and climate change.

- Prioritise compliance activity in areas where pressure is greatest or where specific taxa or target groups are most vulnerable.

- Continue the development and maintenance of the Ningaloo Atlas as the principal tool to make scientific information widely available to managers and the public. This resource will be useful in planning and executing a range of activities for the management of NMP including review of zoning plans, land use planning, identifying sites for direct management action and planning research and monitoring programs.

- Support and engage in further research that will continue to enhance management of NMP as well as other coral reef ecosystems. Specific research needs are raised in individual project summaries, however the following topics are noted as priority areas:
    - Biological and social response to climate change;
    - Ecological connectivity between NMP and coral reef systems off the west Pilbara, Dampier Archipelago to Northwest Cape;
    - Biodiversity of the deepwater soft sediment communities of NMP; and
    - Measuring the effectiveness of compliance programs in NMP

- Review and incorporate, as appropriate, the sampling protocols and reference sites recommended through Node 3 research into WAMMP for the long-term monitoring of the key ecological and social values of NMP.

6 RESEARCH PROJECT SUMMARIES

Following are brief summaries of each individual project prepared by the Principle Investigators including objective, key findings and their implications for management. Communication outputs are included in Section 10 below.

6.1 Project 3.1.1: Deep water biodiversity in NMP

Principle Investigator
Andrew Heyward (AIMS)

Research Team
Institutional Leaders: Andrew Heyward, Jane Fromont (WA Museum), Rob McCauley (CUT), Euan Harvey (UWA)

Key Personnel: Jamie Colquhoun, Ben Radford, Peter Speare, Max Rees, Felicity McCallister (AIMS), Oliver Gomez, Mark Salotti, Shirley Slack-Smith (WA Museum), Ben Fitzpatrick (UWA), Miles Parsons, Iain Parnum (CUT)

Collaborative Project 3.4.1
Lindsay Collins, Emily Twiggs, Sira Tecchiato (CUT)

Project Overview
The Western Australian jurisdiction of NMP extends 5.5 km seaward of the reef crest. Although this deeper water region constitutes a majority of the NMP area, with preliminary indications it may support high biodiversity values, it had not been systematically studied at the time the NMP Management Plan for 2005-2015 (CALM 2005) was established. The zoning of offshore sanctuary zones (see Figure 1) was based on very limited data and first principles assumptions, while the need for additional information was identified as a high priority for future research. This current project sought to address this knowledge gap about the benthic habitats and biological communities in the deeper waters (>20 m) beyond the fringing reef.

This summary addresses the synthesised findings on habitats and biodiversity in the deep waters of NMP. For more detail on biodiversity inventories (Project 3.1.1c), demersal fish assemblages (Project 3.1.1b) and sediments (Project 3.4.2) see the relevant project summary.

Objectives
The aims of the project were to:

- Develop a broad scale characterisation of the of the major benthic habitat types with descriptions of their spatial distribution;
- Establish a baseline biodiversity inventory of the macro-epibenthos through the collection, preservation and identification of dominant components of the major habitat types;
- Produce an improved bathymetry map of the offshore waters of NMP; and
- Through collaboration with and support from WAMSI Project 3.1.4, characterise the surficial sediments and seabed geomorphology of the deeper waters of NMP.

All of these objectives were reviewed in the context of the zoning established in the current NMP Management Plan 2005-2015 (see Figure 1)

Materials and Methods
A number of techniques were employed to characterise and describe benthic habitats and the associated fauna assemblages including:

- Towed video system deployed over 500m transects of the seabed at 375 stations throughout the NMP to establish the nature of the seabed substrata and the dominant components of the macro-epibenthos;

- Benthic sleds towed over 50m transects to sample macrobenthos and create a biodiversity inventory;
- Stereo baited remote underwater video (BRUVS) to survey demersal fish communities associated with the major habitats;
- Single beam depth sounder run along survey lines perpendicular to the coast at a spacing of 500m, the length of NMP to collect improved bathymetry data;
- Multibeam acoustic survey was also undertaken on a trial basis, within the constraints of available budget. This smaller acoustic survey component demonstrated the superiority of multibeam for seabed mapping, but also enabled the line spacing of the single beam approach to be validated; and
- Seabed sediment samples were also collected, in support of project 3.4.1, using a Van Veen grab from the ship at towed video sites throughout the NMP.

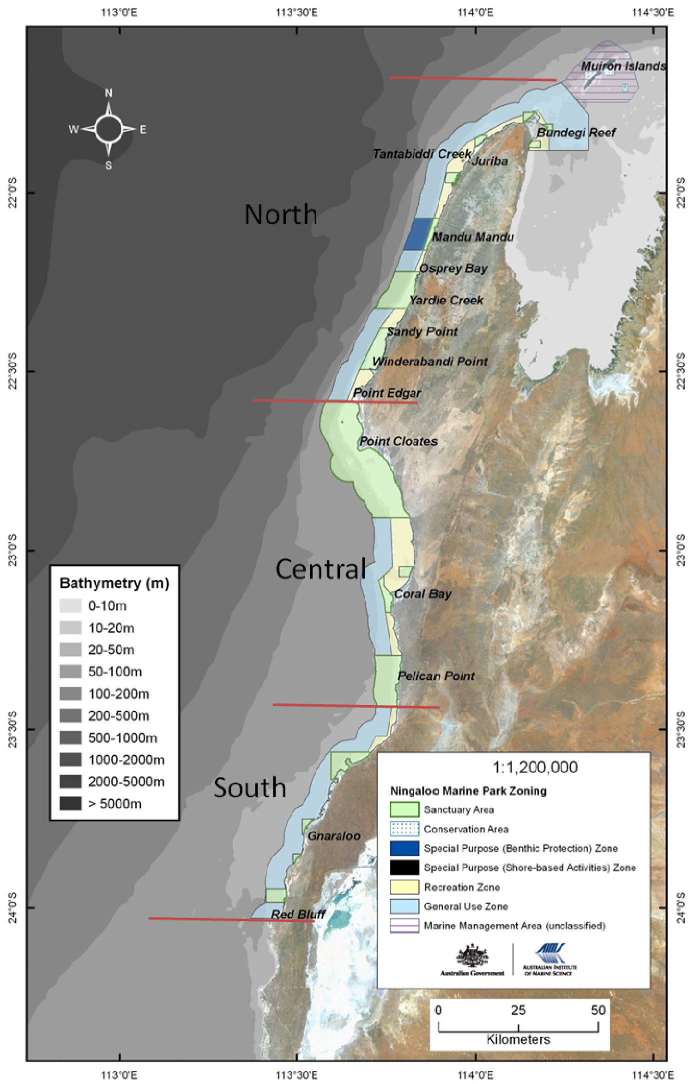

Figure 1. NMP zoning. Red horizontal lines have been added to demark the Northern, Central and Southern regions referred to in this report.

The sampling effort, involving collaboration across four primary institutions, was spread over three years commencing in April/May 2006. While the initial field season used a depth stratified replicated sampling design, subsequent surveys focused on broader coverage, to ensure effort was directed across the entire length of the NMP, albeit with a trade off in sampling density. The focal point of the surveys was benthic habitats in depth strata between 20 and 110 m across NMP. The surveys were conducted on the AIMS research vessels *RV* Cape Ferguson and subsequently RV Solander.

Key Findings

Bathymetry

An improved bathymetry has been developed from the single beam mapping of almost 90% of the offshore areas present in the NMP (Figure 2). This dataset has enabled much more detailed comparisons to be made of depth profiles in various sections of the NMP, beyond the general picture of a very narrow shelf margin in the northern and a wide, more shallow shelf in the southern half. Figures 3, 4 and 5 provide graphical summaries of how the distribution of depth zones varies in the northern, central and southern sections and the degree to which these are proportionally represented in sanctuary zones.

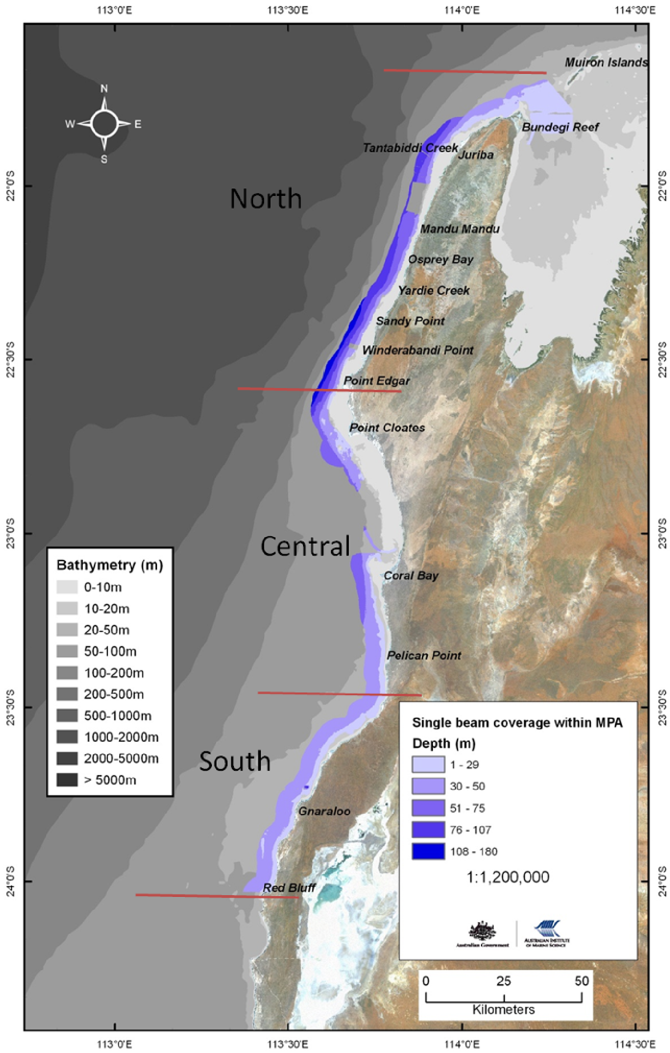

Figure 2. Single beam coverage and derived bathymetry for Ningaloo Marine Park.

It is clear that the distribution of depth zones varies significantly in the northern, central and southern areas of the NMP and that the depth zones, at least when grouped into 10m contours, are represented unevenly in the offshore sanctuary and special purpose zones. The exception is in the Central region, which contains the very large offshore sanctuary region centred around Pt. Cloates (Figure 1).

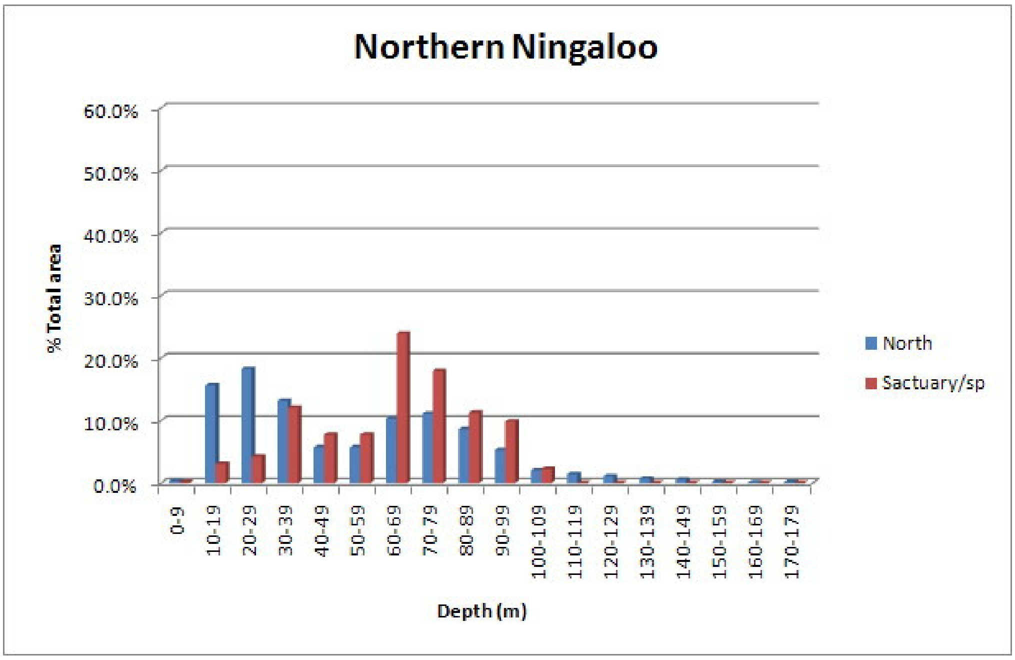

Figure 3. Relative distribution of depth in 10m intervals in the northern section of the NMP and a comparison of the relative distribution of depth zones in the associated offshore sanctuary and special purpose zones.

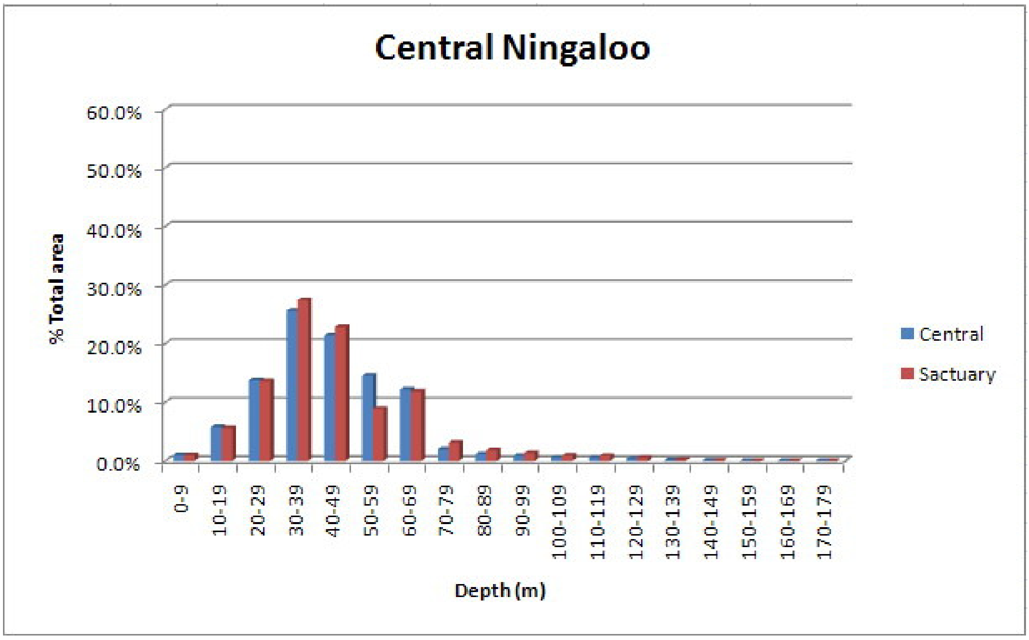

Figure 4. Relative distribution of depth in 10m intervals in the central section of the NMP and a comparison of the relative distribution of depth zones in the associated offshore sanctuary zones.

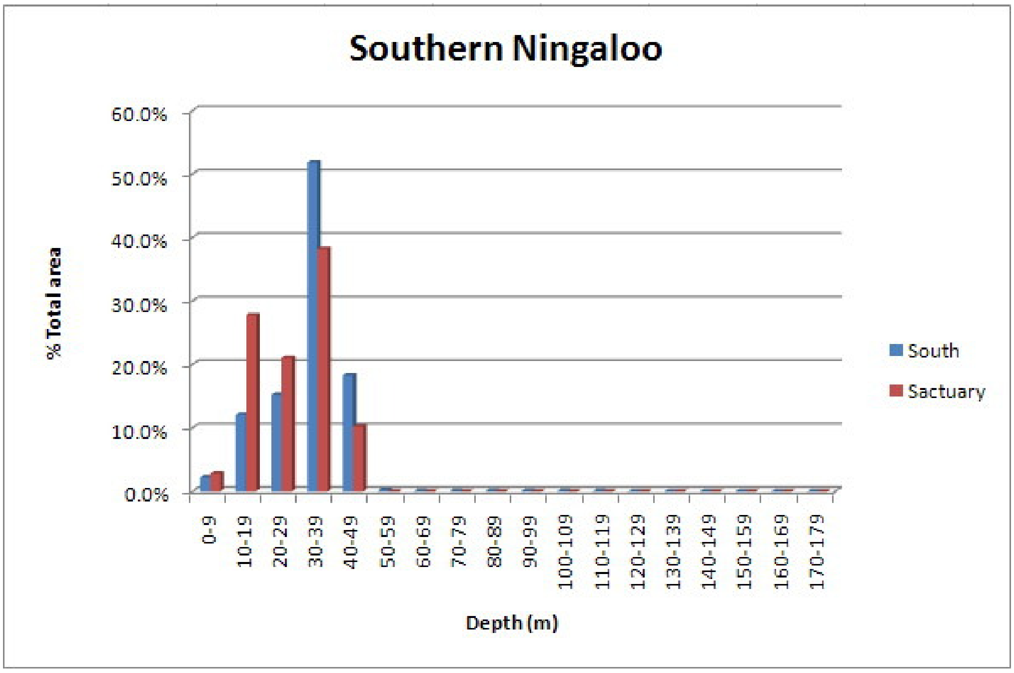

Figure 5. Relative distribution of depth in 10m intervals in the southern section of the NMP and a comparison of the relative distribution of depth zones in the associated offshore sanctuary zones.

Habitats, geomorphology and geology

The major habitat and substrate types have been characterised using live towed video. Three hundred and seventy five video transects, each of approximately 500m length were completed, typically at each of three cross-shelf stations every 5km along the reef, to provide a broad initial assessment of the seabed. Integration with the improved bathymetry, together with insights into the geology and geomorphology from project 3.4.1 have enabled an initial broadscale view of the major habitat types and distributions.

Of the four major substrate classes, sand, in various forms, constitutes the major substrate component of the deeper waters of the NMP, representing approximately three quarters of the total (Figure 6). The other substrates, essentially a mix of various rubble, reef platform and sand combinations, or consolidated rocky reef type substrates provide the remainder but are not distributed evenly.

There are clear depth gradients across the shelf in relation to major benthic habitat distributions. These patterns were additionally influenced by latitude due to the varying shelf width and changing seabed slope along the length of the NMP. In spatial terms, the greatest diversity of habitats is observed in the inner part of the offshore NMP, between the reef slope and depths of approximately 60m. In this zone nearly all the major habitat types can be encountered. The other areas of between 60-100m+ typically consist of various sandy areas and low to moderate relief rocky outcrops and ridgelines. Overall, 5 key habitat types were identified based on substrate, depth and biodiversity. These are:

a. **Sandy habitats**: formed the spatially dominant component of the deeper NMP. Large expanses of flat or slightly rippled medium to fine sand, sometimes interspersed with coarse biogenic rubble or shell grit, were

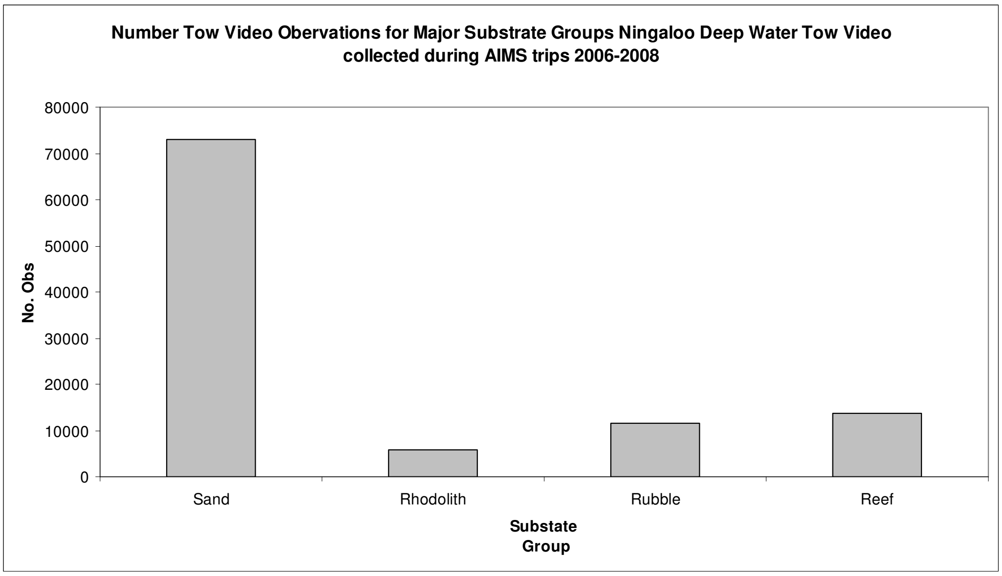

Figure 6. Proportion of the major substrate classes throughout the NMP, based on the number of observation records logged with towed video. The categories shown include several broad classes of substrate, Sand = all types of sand dominated substrates, including fine & coarse sand, ripples and waves; Rhodolith = rhodolith dominated seabed areas, where fairly consistent 25-75mm rhodoliths covered in calcareous red algae were dominant but could include a mix of other rubble, rock and sand; Reef = includes all consolidated substrate including high relief coral reef and low relief ridges.

encountered in most depths throughout the Park. Acoustic surveys indicate some of these sand fields may be part of larger offshore dune systems and also reveal alluvial fan type deposits adjacent to large openings in the reef to the lagoon.

b. **Coral dominated habitat**: Typically, consolidated biogenic reef extends from the reef crest seawards, often broken into spur and groove or separated ridge features. This type of habitat is most commonly dominated by Scleractinian corals, which vary in abundance but exhibit a general decline in both abundance and diversity as depth increases to around 40m. Beyond 35-40m corals become patchy in distribution along the fore reefs and generally remain a subdominant component of the benthos until disappearing almost completely beyond 50m depth. It is important to note, however, that in southern areas of the NMP, the nearshore fore reef habitats in 20-35m, while sometimes supporting significant coral cover, can equally feature moderate to high densities of filter feeders or a mixture of both.

c. **Rubble zones**: At the base of the fore reef and sometimes extending well offshore to depths of around 55m, extensive rubble fields frequently occur. Most commonly the rubble stones are rhodoliths of 40-60mm diameter, interspersed with sand, macroalgae and smaller invertebrates. These rubble/rhodolith fields have been recorded in most areas of NMP, although their extent varies from a narrow band at the base of consolidated reefs to very large fields. One of the most extensive areas noted was within the Pt Cloates sanctuary zone in depths of 35-55m

d. **Low relief ledge and rocky substrate filter feeders**: Erect sponges and, to a lesser extent cnidarians, such as gorgonian fans and sea whips are a common and notable feature at varying depths across the shelf throughout the NMP. These tend to be highly diverse filter feeding communities and are frequently encountered along north-south running ridges which may be remnant coastal features. Sponge gardens in the 60-80m depths within the Mandu Mandu special purpose zone are an example. In addition to growing on top of hard substrate, low relief ledges and broader patches of hard ground pavements, sometimes the filter feeding biota appear to emerge from soft sandy sediments. Presuming these organisms need stable hard substrate to get established, this is likely to be a consequence of fine sediment being highly dynamic and moving over established community areas, or the macrobenthos itself causing fine sediment to settle and accumulate.

e. **Rocky ridges and pinnacles**: Larger lumps and ridge features have been noted at various places and may be considered, due to their size and exaggerated vertical relief, to be an additional habitat type. Usually these seabed features appear to be highly consolidated rocky substrates and support medium to high densities of macrobenthos, especially sponges. The two most notable areas where these features have been observed to date are within the central Pt Cloates Sanctuary Zone and in the south between Gnaraloo and Red Bluff. In the Pt Cloates area some pinnacles and mounds are up to several hundred meters long and can range in height from 3-15m. On the larger pinnacles the ridge tops can be dominated by corals, which give way to filter feeders down the slope then transition into rubble zones. In the Gnaraloo-Red Bluff area these larger ridge features are less numerous, but there is also a broader expanse of consolidated and slightly elevated pavement which can support dense benthic communities.

Biodiversity inventory

Beyond the immediate fore-reef area, where corals and fleshy algae can be important, the broader offshore NMP is largely sand and silt, interspersed with moderate amounts of consolidated substrate, typically in the form of patchy outcrops or extended low relief ridges. In these areas the harder substrates support moderate to high abundance of sessile benthos, dominated by filter-feeding invertebrates, most particularly the sponges (see Figure 7). It should be noted though that soft-sediment communities were not sampled as part of this study, only communities on hard substrates.

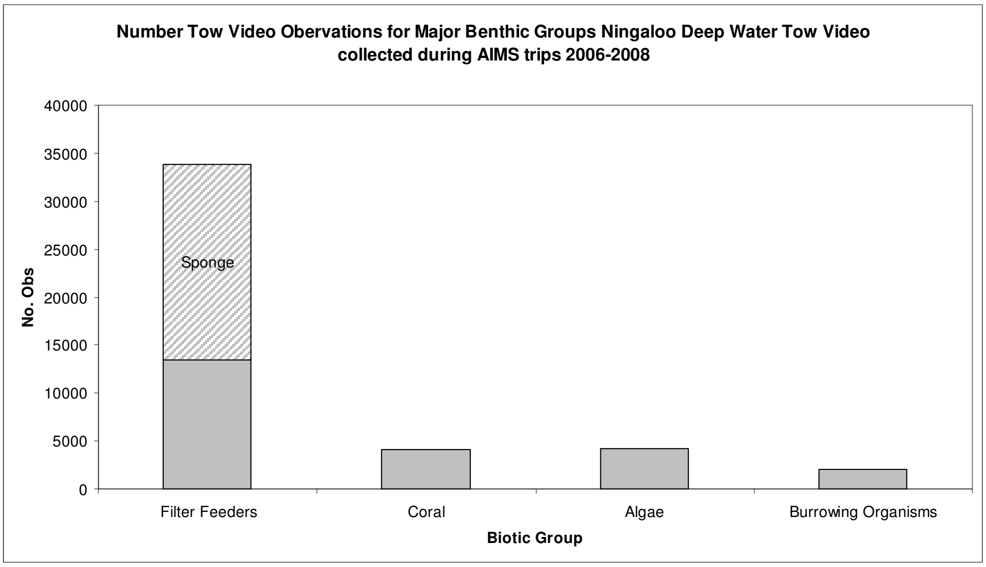

Figure 7: Proportion of the major biotic classes throughout the NMP, based on the number of observation records logged with towed video.

Identification of the biodiversity sampled from the deeper waters of the NMP has been based on traditional museum-based analysis of sessile invertebrates collected with epibenthic sleds and an image analysis approach to fish community characterisation using deployed baited video. It should be noted that the sampling methods used in this study are likely to grossly underestimate infaunal biodiversity associated with areas of sand or other unconsolidated substrata. The biodiversity associated with the offshore benthic habitats has been formally characterised to species level where possible. Nearly 1200 species (844 invertebrate, 319 fish) were identified from initial benthic sled and BRUVS sampling. Additional species will be added to the inventory as final Museum and BRUVS data are processed. See Projects 3.1.1b and 3.1.1d for further detail on these species groups.

The WA Museum has made significant progress in identifying the non-reef invertebrates collected at 145 stations in depths of 18-144 metres. Most species were tropical endemics of Australia, with few southern species collected. The echinoderms had a large tropical shelf component and many coral reef species, but also numerous new species and extensions of biogeographic distributions. It has been more difficult to determine the significance of the sponges in a global context due to the lack of species names, but many species do appear to have localised distributions. Localised distributions were also common for the molluscs, although a lot of the molluscs are known species. In general there appears to be a relatively high level of endemicity of the fauna on the shelf adjacent to Ningaloo Reef.

Sponges were strongly represented (155 taxa to date) and also contributed the majority of biomass in most benthic samples, but diversity was also high amongst molluscs (236), echinoderms (227) and crustaceans (226). New species were discovered in most major groups. This study has resulted in the first comprehensive collection of sponges from this region (Heyward et al, 2010) and has provided a basis for ongoing taxonomic and biogeography studies of these dominant filter feeders. Detailed analysis of biodiversity from this project has recently been presented by Fromont et al (2011) and is summarised in this report (Project 3.1.1d). Subsequent additional biodiversity collections and characterisation were carried out in the Ningaloo region under the auspices of CERF, leading to a large expansion of the species list and a basis for comparison with this project (Schoenberg & Fromont, in press).

There was clear partitioning of fish assemblages between habitat/depth categories, with examples of different size classes of the same species occupying different parts of the shelf and of species within a family being dominant in certain habitats. Higher order predators, including species of Lethrinidae, Carangidae, Serranidae and Lutjanidae were found associated with most habitat types and their abundance and length increased with water depth. There was evidence for strong ecological linkage between shallow reef/lagoon areas and deeper water habitats for different life history stages of some fish species.

Some coral reef species typically noted in shallow lagoon areas were found to be also capable of utilising the offshore filter feeder habitats. These findings suggest many species commonly associated with coral reefs utilize a broad range of depths and habitats across the continental shelf with varying degrees of specialization.

In addition to the influence of substrate type, depth and latitude appear to be significant factors associated with differences in the biological assemblages encountered throughout the deeper waters of NMP. In general, species groups for the three phyla (sponges, echinoderms, molluscs) were aligned with areas across the region. Stations in the northern area, which contains the narrow shelf environment, often grouped separately from the other areas. The Muiron Islands stations sometimes grouped with the central and southern areas, perhaps because these areas all have a widening shelf environment.

Management Implications

This study has provided baseline information on bathymetry, habitats and biodiversity in the offshore waters of NMP and provides a resource that management can draw on for long-term management of NMP and its marine resources. It has produced a number of outputs that are directly relevant to management needs and uses including GIS based spatial layers of habitats and bathymetry based on the single and multibeam acoustic surveys and associated habitat modeling using physical surrogates for biodiversity. The resulting maps provide an accurate and georeferenced guide to habitats and the underlying geomorphic features that are associated with their distribution. In addition, this project has compiled a library of quality photographs and video of spectacular marine benthic fauna.

The confirmation of very high biodiversity values associated with benthic habitats in the offshore region of the NMP supports not only the recognized status of NMP as a biodiversity hot spot, but also the rationale for enhanced conservation measures, such as sanctuary or benthic habitat protection zones, to protect representative areas of the deeper water habitats.

Significant species differences found between the different regions of NMP suggest that southern, central and northern areas may individually make equally important contributions to the overall biodiversity values of the park. For example, while benthic biodiversity is high throughout NMP, the biodiversity rich areas differ for taxa along the reef. While most species, communities and habitat types are protected to some degree through the existing zoning, the distribution of area within the offshore sanctuary zones is biased towards the central and northern regions and a more equitable distribution of area across the length and breadth of the NMP may yield a more comprehensive and representative conservation strategy.

Consideration should also be given to conservation management strategies between the Commonwealth and Western Australia adjacent to the Muiron Islands. The preliminary results of this study suggest significant sponge garden communities there, which appear to become increasingly diverse and abundant at the outer boundary of State waters and into Commonwealth waters, which currently are not included in the Commonwealth marine park boundaries. Evidence from this study suggests that, to provide adequate protection to benthic biodiversity and associated communities, would require amendments to the current zoning scheme either through amending the boundaries of some deep water sanctuary zones or adding several benthic habitat protection zones.

Recommendations

Consideration should be given to amending the management framework for NMP so that it provides representative protection to deep water biodiversity through either extension of current sanctuary zones or addition of benthic habitat protection zones in the southern and northern regions and adjacent Commonwealth waters where rich and unique sponge gardens have been identified yet are currently afforded very limited protection.

Acknowledgements

We would like to thank staff from the Department of Environment and Conservation, Exmouth District, the Exmouth Harbour Master and collaborators in Project 3.4 for their assistance.

Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Products and Formats

Cross and along shelf profiles of water depth using single beam echo sounder of all survey transects. Data used to identify deep water habitats and in broad scale habitat mapping. – ESRI shapefiles

Video from towed video transects of benthic habitats. Data used to identify deep water habitats and in broad scale habitat mapping.

Accessibility
Data, samples and derivatives from this project are held by the partner research organizations. Copies of all data have been provided to WAMSI and are accessible through the AIMS server.

Knowledge Transfer

This study is an Inventory project that provides initial and baseline information on biodiversity assets within NMP. It will be of use to DEC staff with a role in marine park planning, monitoring and operational activities. Of particular importance is the transfer of information that will be used to support the placement and necessary amendments to the sanctuary zone scheme.

6.2 Project 3.1.1b: Deep water demersal fish distribution and abundance

Principle Investigator
Euan Harvey (UWA Oceans Institute and School of Plant Biology)

Research Team
Ben Fitzpatrick (UWA), Stephen Newman (DoF, WA), Mike Cappo, Ben Radford, Andrew Heyward (AIMS)

Project Overview
There is very little information on the distribution of demersal fishes on the seaward side of the reef crest in NMP. However, this area is where a significant proportion of the boat-based recreational angling effort is now focused. In 1991 the shelf and slope fish assemblages were sampled by trawling between depths of 200 and 1500 m between 20° and 35° S (Williams et al 2001). They found distinctive fish assemblages with depth and latitude as well as high diversity and low abundance of many species.

Sampling of demersal fishes with Baited Remote Underwater Stereo-Video Systems (Stereo-BRUVs) undertaken as part of this project in the northern section of NMP showed there were distinctive cross-shelf patterns that extended from the inner lagoon out to the 100 m bathymetric contour on the continental shelf (Fitzpatrick et al. unpublished data). Some species exhibited cross-shelf changes in ontogenetic structure. This research project aimed to extend the depth range and the latitudinal gradient observed in previous studies to the central and southern sections of NMP and across the continental shelf.

Project 3.1.1 collected data on the benthic habitats, sediments and bathymetry along the length of NMP and identified a number of benthic habitats that were targeted for fish sampling (Heyward et al. this volume).

Objectives
The objective of this research was to assess the finfish biodiversity of the deeper waters seaward of the reef crest in NMP. In particular we were interested in determining: 1) whether there were differences in the fish assemblages from the outer slope of the reef crest to the edge of the continental shelf, and 2) between the northern, central and southern parts of the NMP.

Secondary objectives were to identify patterns in the relative abundances and length (as an indicator of age class) of selected target and dominant species.

Materials and Methods
Stereo BRUVs were deployed in March-May 2009 between depths of 15 and 350 metres according to the sampling plan developed using bathymetry and textural datasets derived from the bathymetry (Project 3.1.1 – Heyward et al. this volume). A total of 656 useable 1-hour samples were collected from sites in the northern, central and southern regions of NMP (Figure 1).

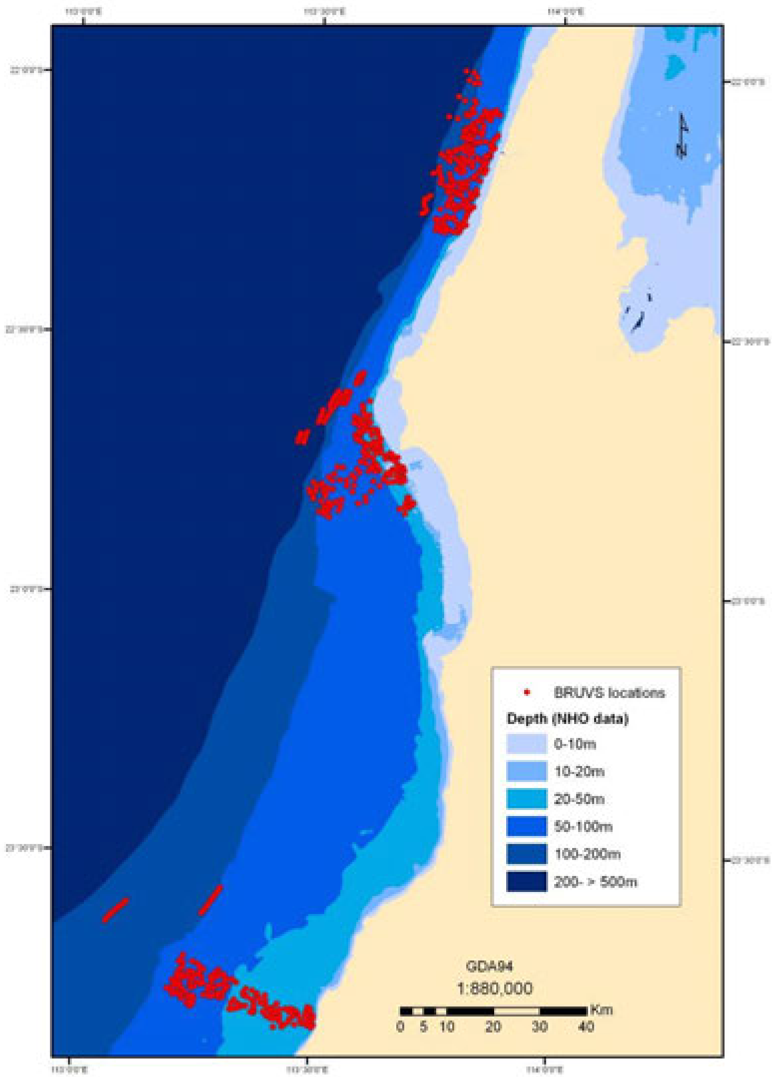

Figure 1. The locations of stereo BRUV deployments in the northern, central and southern sections of NMP.

Key Findings

From 656 stereo BRUV deployments we recorded 365 species and 26,088 individual fish. Most of the 365 species recorded were rare or uncommon, occurring in only a very small percentage of the sites. There was an average of 9.8 ± 6.8 (s.d.) species per site, ranging from 1 to 46, with a median of 8 species. Only ~9% of sites had comparatively high species richness (≥20 species). Just over 90% of the species were recorded at less than 36 of the sites, and ~80% were recorded only between one and three times. Only about 3% of the species were moderately prevalent, occurring in ≥20% of the sites, and none were sighted at more than 50%. The three most prevalent species were the starry triggerfish *Abalistes stellatus* (305 stations; 46.5%), the iodine sea bream *Gymnocranius grandoculis* (282; 43%) and the silver toadfish *Lagocephalus sceleratus* (212; 32.3%).

Multivariate regression trees identified 14 distinctive fish assemblages (Table 1). There were 3 coarse groups of assemblages based on depth: the photic (shallow (15-30 m)), mesophotic (31-89 m), and subphotic (89m to deeper than 201 m). Within the mesophotic zone, there were 3 groupings - shallow mesophotic (~32 m), mesophotic (~47 m) and deep mesophotic (< 88 m). “Gardens” of sessile invertebrates (presumably sponges, gorgonians and soft corals) characterised the benthic fish assemblages in all depths from the shallow, photic to the subphotic zone on the shelf.

The benthic fish assemblages characterised by the presence of macroalgae alone, or in the presence of sessile invertebrates, were present in the shallow photic zone – but also extended beyond 47 m in the mesophotic zone. The deep waters on the lower slope (10 – 47.1m), the slope (47.1 – 140m), and the shelf (>140m) itself formed distinctive assemblages.

Fish assemblages	***# of stations***	***Richness Range (mean ± std.dev.)***	***Abundance (ΣMaxN) Range (mean ± std.dev.)***
Very deep lower slope	68	0-7 (3.1 ± 1.6)	0-106 (17.2 ± 18.3)
Deep lower slope	45	2-9 (5 ± 1.6)	4-60 (20.8 ± 13.4)
Subphotic shelf megabenthos	42	4-20 (9.3 ± 3.4)	7-134 (26.1 ± 20.3)
Subphotic outershelf sand plains	59	4-18 (9.1 ± 3.4)	8-64 (22.1 ± 12)
Subphotic midshelf sand plains	77	4-19 (9.1 ± 3.2)	7-512 (44.1 ± 64.7)
Deep mesophotic algae/sand	160	1-18 (7.4 ± 3.2)	1-1528 (35 ± 123.1)
Deep mesophotic megabenthos	23	5-20 (11.9 ± 4.6)	7-82 (31.3 ± 18)
Inshore shallow mesophotic sand	55	1-16 (5.4 ± 3.5)	1-383 (49.8 ± 78.1)
Offshore shallow mesophotic sand	22	4-22 (11 ± 5.3)	10-776 (77.1 ± 160.3)
Inshore shallow mesophotic gardens	14	8-24 (16.4 ± 5)	16-201 (73.5 ± 50.9)
Offshore shallow mesophotic gardens	14	7-26 (17 ± 5.2)	9-208 (99.9 ± 66.4)
Mesophotic gardens	43	4-28 (13.4 ± 6.5)	5-232 (51.3 ± 48.6)
Shallow gardens	9	10-26 (19.2 ± 5.1)	29-223 (80.2 ± 58.3)
Coral dominated	25	7-34 (19.2 ± 6.7)	14-223 (83.2 ± 53.6)

Table 1. Distinctive fish assemblages and their associated species richness and relative abundances.

Species richness and the relative abundance of fish declined with depth. There was some evidence that there were differences in the fish assemblages between the northern, central and southern zone sampled. These differences were driven partly by differences in depth with the northern zone dropping onto the continental slope within several kilometres of the reef crest. In the southern zone the continental shelf extends much further offshore, for example, at a distance of ~30 km offshore we were sampling in depths of 100m.

There was some evidence for size-based differences between areas and between onshore and offshore samples. For example, pink snapper *Pagrus auratus* was larger in the southern zone (at the northern end of their abundance range) and larger fish of that species were found in deeper water. Conversely, norwest blowfish *Lagocephalus sceleratus* displayed a tendency for larger fish to be inshore.

Management Implications

We found 14 distinctive fish assemblages between the bottom of the reef crest to the outer continental shelf slope with evidence of ontogenetic partitioning across the shelf habitats. While the current zoning scheme protects a number of these species and assemblages, others associated with specific benthic habitats are not comprehensively represented within the current sanctuary zone scheme. The information should be taken into account in the next review of the NMP Management Plan.

This study provides valuable baseline information on the distribution and relative abundance of demersal fishes. This information will also be useful in identifying key fish biodiversity indicators for long-term monitoring of ecosystem health.

Acknowledgements

We would like to thank the skipper and crew of the RV Naturaliste and Glenn Hill, Colleen Quirk and Brett Venables from the FV Olympia for field support and advice.
Heather Taylor, Alex Grochowski, Sam McMillan, Claudio Fiorentini, Derek Walker, Paolo Vota provided invaluable field support. We would also like to acknowledge GeoSciences Australia and CSIRO Marine for providing access to multi-beam data from the Ningaloo shelf and slope area, which assisted with the sample design

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Datasets and formats include: video imagery of BRUV samples from sites at Cloates, Osprey and Mandu; datasets on fish species, abundance, size and habitat derived from BRUVs.

Data and video imagery are available through the iVEC database.

Knowledge Transfer

This study is a Baseline project that provides initial and baseline information on biodiversity assets (demersal fish) within NMP. It will be of use to DEC staff with a role in marine park planning, monitoring and operational activities.

6.3 Project 3.1.1c: Deep water benthic biodiversity of NMP

Principle Investigator
Jane Fromont (WAM)

Research Team
Lee Betterridge, Oliver Gomez, Andrew Hosie, Loisette Marsh, Mark Salotti, Alison Sampey, Shirley Slack-Smith, Corey Whisson (WAM); Jamie Colquhoun, Andrew Heyward, Ben Radford, Christine Schönberg, Tyrone Ridgway (AIMS).

Project Overview
Even though filter feeding communities are now considered significant and important habitat types, in Australia, biological studies on these communities have been limited (Schönberg *et al.* 2011, Fromont *et al.* 2011). Little is known about the biological and environmental reasons for the distributions of extensive deeper water filter feeder communities, although in shallow water studies of highly diverse areas, substrate type, aspect and depth were found to be important (Fromont *et al.* 2006). Prior to this study, towed video footage by the Australian Institute of Marine Science (AIMS) indicated that sponge and filter feeding communities were diverse and variable in the deeper waters off Ningaloo reef. However, the distribution and species composition of these communities was not known, and addressing this knowledge gap was considered essential to informing future management of NMP. The major objective of this study was to characterize the species occurring in the deep water communities of NMP. Additionally, the project documented the dominant species in the communities, the distribution of the habitats along the reef, determined the significance of the biodiversity, and examined whether the communities were adequately represented in sanctuary zoning scheme for the marine park.

Materials and Methods
Sampling stations were determined by AIMS with reference to acoustic generated maps and video footage that indicated different habitat types in the study area. Standardised field collecting methods and preservation protocols allowed for the biodiversity data to be directly comparable between stations and collecting years in 2007 and 2008 (methods were still being developed in 2006 and were not consistent with the latter years). Sampling was quantitative with sled tows standardised as much as possible to sample 50 metre lengths of the substrate with latitude, longitude and depth recorded at the start and end of each tow. Soft sediment habitats were not sampled and outcropping reef, which occurred in some areas, was difficult to sample, as the sled could bounce on this substrate. Stations were selected latitudinally along the reef between the Muiron Islands and Red Bluff (Figure 1). A total of 145 stations were sampled between 18 to 144 metres depth by sled (49 in 2006, 12 in 2007 and 84 in 2008). Although all species of all phyla were collected, only the dominant sponges, based on wet weights determined in the field (≥1 kg), were identified.

Species richness was determined using presence/absence data, and a hotspot analysis (Getis & Ord, 1992) determined areas of high diversity for the taxa surveyed. Redundancy analyses provided clues to the major drivers of the taxon distributions.

Key Findings
A total of 155 taxa of dominant sponges, 227 taxa of echinoderms, 236 mollusc taxa, and 226 crustaceans (brachyurans only) were identified. Cnidarians, bryozoans and ascidians were recorded as present or absent at each station. Many of the taxon groups contain species new to science. For example, in the echinoderms one new species of urchin,

possibly 14 new species of seastars, 3 new species of brittle stars and at least one new species of holothurian were reported. In addition, as a result of this study, many previously known species were reported for the first time from this area, thus increasing their known geographic distributions.

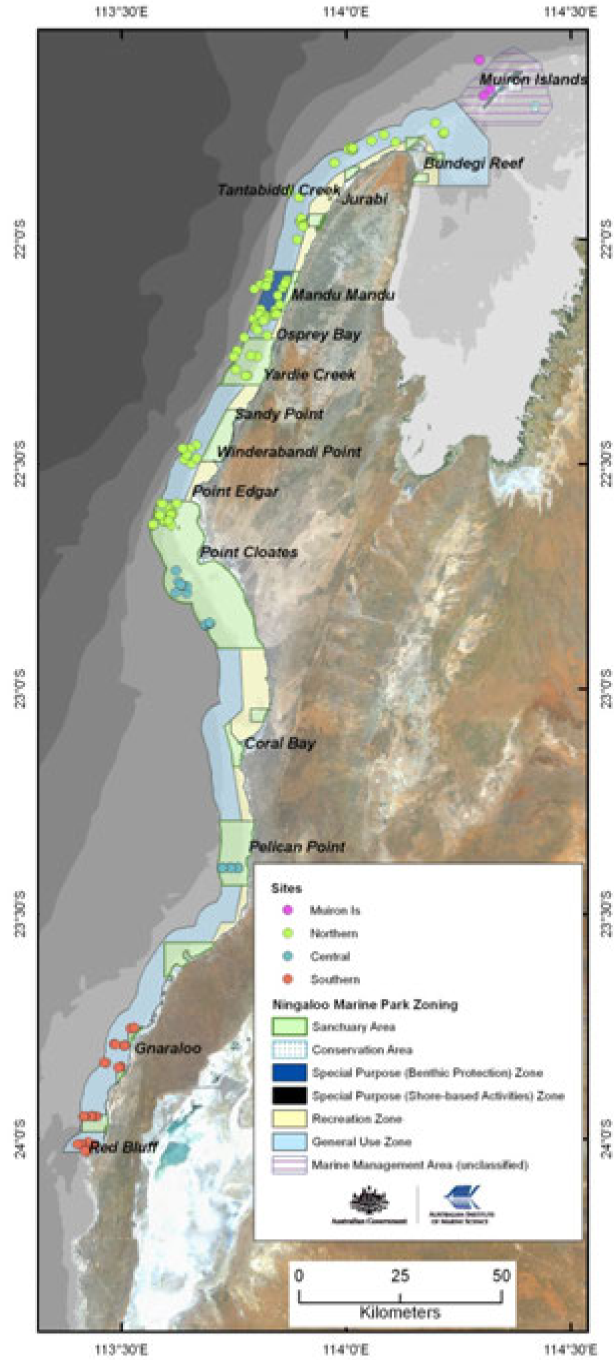

Figure 1. Stations sampled for collection of deepwater benthos, from 2006-2008.
In general the fauna consisted predominantly of tropical shelf or reef species with a smaller southern temperate component.

Species richness and turnover was high. Overall species richness, and richness within taxon groups, changed along the coast from north to south (Figure 2).

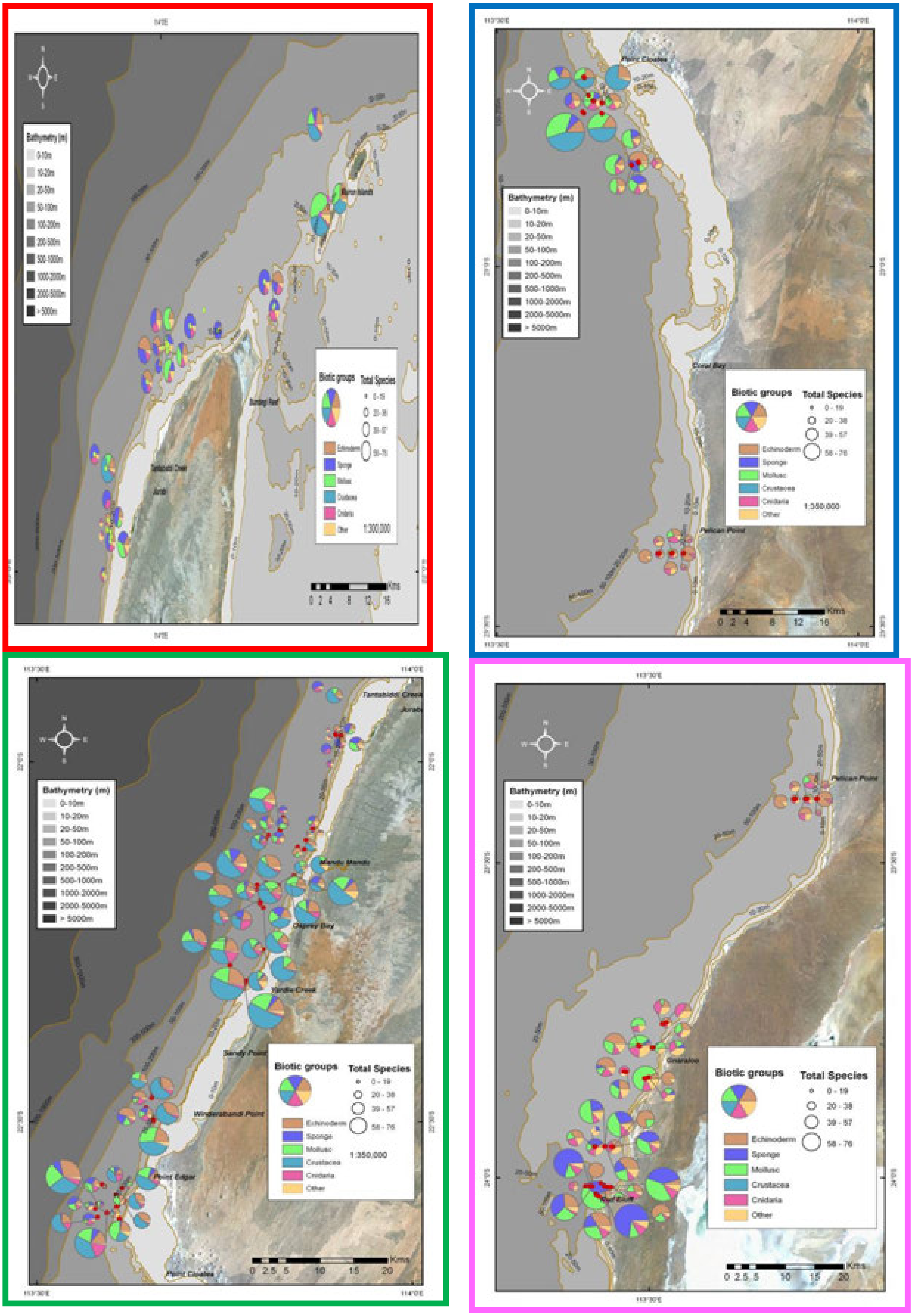

Figure 2. Patterns of species richness of targeted taxon groups along the Ningaloo reef tract. The category 'other' includes principally bryozoans and ascidians.

Red Bluff area was identified as a hotspot for sponges based largely on the presence of species at this site not reported further north. A hotspot for both echinoderms and molluscs was the reef region around Yardi Creek, with Winderabandi Point and the Muiron Islands identified as hotspots for echinoderms and molluscs respectively.

For all taxon groups redundancy analyses indicated that latitude, longitude, and depth significantly influenced distribution patterns of the taxa examined. In all taxon groups the southern region (Gnaraloo and Red Bluff) separated from the more northern regions. Frequently the central region (Pelican Point to Point Cloates) was intermediate between the north and south, suggesting this region was an overlap zone for species distributions.

Management Implications

This study provides valuable baseline information on the distribution of deeper water species along the Ningaloo reef tract. The dataset allows for comparison of deep water benthos at NMP with other regions to the north and south along the Western Australian coastline.

In general the study found a very high level of benthic biodiversity present within Ningaloo NMP, further supporting its status as a biodiversity hotspot as recognized through its recent acceptance as a World Heritage site. For management purposes, it is equally important to note that different areas within the marine park represent biodiversity hotspots for different taxa. Thus management strategies such as zoning need to take this into account when developing a comprehensive and representative plan. Overall, the biodiversity hotspots identified in the deep waters of NMP were frequently within sanctuary zones. However, the important sponge gardens around Red Bluff, and the rich sponge habitat at the mouth of Exmouth Gulf, are not currently protected in sanctuary zones. Additional protection for echinoderms and molluscs would be assisted by extending the inshore sanctuary zones between Winderabandi Point and Sandy Point, and off Yardi Creek, further offshore. The Muiron Islands was also seen to contain significant biodiversity, even though few stations were sampled from this area. Additional sampling would clarify the species present and the richness of this marine management area.

As a result of this study it is now apparent that sponges dominate the filter feeding communities off Ningaloo Reef. Dominant sponge species changed latitudinally along the reef tract, for example, the temperate species *Spheciospongia* cf. *papillosa* only occurred southward below Amherst Point, and *Ecionemia* sp. dominated north of Point Cloates. These latitudinal differences mean that Ningaloo NMP cannot be viewed as a continuous environment even within a taxonomic group, but one that contains different species and assemblages along its length. Management will need to take this into consideration to ensure adequate protection to all assemblages throughout the Park.

Finally, a number of the dominant sponge species are large, morphologically distinct and can be identified using video techniques. Such techniques could be used in a cost-effective long-term monitoring program to detect changes in community structure and composition.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Analysis of sled samples including biomass weight, dominant taxa weight, species id,. Specimens were collected from all invertebrate taxa sampled.

Data is stored in a database held at the Western Australian Museum. This data will be placed on the WA Museum website when the paper is in press. Summary information will be available on the Ningaloo Atlas (www.ningaloo-atlas.gov.au) and the WA Museum website (www.museum.wa.gov.au).

Knowledge Transfer

This study is an Inventory project that provides initial and baseline information on biodiversity assets within NMP (deep water filter feeder communities). It will be of use to DEC staff with a role in marine park planning, monitoring and operational activities. Of particular importance is the transfer of information that will be used to support the placement and necessary amendments to the sanctuary zone scheme. Additionally, this project has produced interesting resources suitable for community and public education about the importance of these communities and species.

6.4 Project 3.1.2: Methods of monitoring the health of benthic communities - Fish recruitment.

Principle Investigator
Martial Depczynski, (AIMS)

Research Team
Mark Case, Jamie Colquhoun, Tim Cooper, Andrew Heyward, Rebecca O'Leary, Ben Radford, Paul Tinkler (AIMS), Shaun Wilson, Thomas Holmes, James Moore (DEC)

Project Overview
Effective ecosystem management relies on continually assessing trends and changes in resident organisms (i.e. adaptive evidence-based management). Of particular importance are those organism groups that serve vital roles and functions within these ecosystems. Corals and fish are perhaps the most visually conspicuous and critical ecological components of coral reef ecosystems. Together, they provide essential habitat and perform a host of important tasks that maintain the health and integrity of these systems. Intricately linked to coral reef food webs, these organisms have significant value in generating, storing and providing energy within reef ecosystems. Given the importance of these roles and the responsibility of managers to maintain the health of these systems, it is vitally important that changes in these organisms are detectable. However, without a historical backdrop of baseline information, it is impossible to determine whether changes in these parameters are due to natural variability or are cause for concern.

At the core of marine biodiversity and ecosystem maintenance is the annual replenishment of individuals (i.e. recruitment). Most marine organisms have a bipartite life cycle where larvae recruit into their juvenile and adult habitat from the open ocean. For coral reef ecosystems, annual recruitment is concentrated over just a few months of the year for most fish and coral species. Conveniently, this also provides a metric by which we can measure the potential success of an ecosystem on an annual basis allowing us to forecast into the future and begin to understand the properties that govern replenishment patterns at local scales. For this information to be useful though, baseline information on abundance, species identity and structure across space and time is required to be able to differentiate between natural variability and changing trends.

Objectives
This project had two main aims:

- Design parameters for a long-term monitoring program at NMP for coral reef fish communities including; baseline data, coral and fish recruitment relationships and the required levels of spatial and temporal replication; and
- Develop a better understanding and assess the effectiveness of management zones (i.e. sanctuary versus non-sanctuary) in supporting recruitment.

To achieve these objectives this study set out to provide baseline data on current levels of fish recruitment using a variety of methods and to establish fish recruitment monitoring sites at an appropriate spatial and temporal scale.

Broadly speaking, methods to record fish recruitment fall into two main categories; the use of aggregation devices such as light traps or some type of net to capture newly arrived recruits just before they reach the reef (e.g. Doherty 1987, McIllwain 2003) and underwater visual censusing (UVC) of newly arrived individuals on the reef itself (e.g.

Dorenbosch et al. 2006). There are advantages and disadvantages to both. This study used UVC of juveniles on the reef as its method of choice because 1) light trapping and other aggregation devices are very selective, 2) light traps and crest nets are logistically difficult to work with at NMP, and 3) juveniles that have already settled on the reef are a more accurate measure of the individuals that will have an impact on ecosystem well-being through their trophic and reproductive activities.

We evaluated a range of UVC methods for censusing juvenile fishes including block designs, on-reef fish aggregation devices and different transect sizes. Extensive comparisons were also initially made on the consistency of inter-observer estimates of habitat characterisation, fish size and abundances to provide an understanding of the challenges that might present themselves in the transition towards an ongoing long-term monitoring program (see Depczynski et al. 2009 for full details and considerations).

Key Findings

This study found that the use of UVC based on 30 x 1 m belt transects to measure annual fish recruitment rates at NMP provided the highest level of precision, were logistically simple to use and therefore able to cover larger areas within the same time frame. The report provided the following insights on the degree of skill needed to conduct accurate surveys of juvenile fishes;

- Gross percentage habitat characterisation estimates were immediately within an acceptable 15% between all four observers;
- Fish size estimates required 3-4 trials of 9 floating fish models before variation among observers reached an acceptable level (<5mm total length accuracy);
- There was no statistical difference between observers for juvenile fish abundances along identical transects;
- There was, however, a statistical difference for species richness but this was due to one of four observers and was quickly rectified; and
- It took a considerable length of time before all observers could accurately identify all NMP juvenile fishes to species.

This information suggests that a regular team should conduct surveys each recruitment season and that calibration between observers and some basic taxonomic knowledge (to family level at the very least) is important. The problem with accurate species identification has also largely been addressed through the development of NMP specific underwater “cheat sheets” that contain images of all the most common juvenile fishes encountered at NMP throughout the 3 year duration of the study.

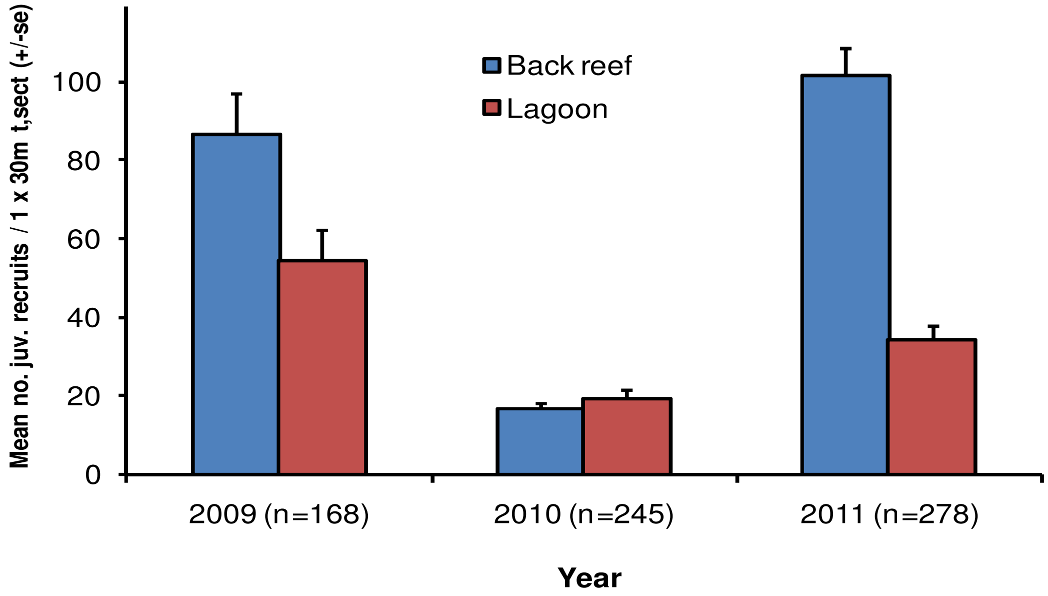
The abundance, species richness and assemblage structure of juvenile fishes was quantified at 20 locations extending from Bundegi to 3-Mile Camp, some 280km of the NMP coastline. Within locations, both back reef and lagoonal reef zones were censused including sanctuary and recreational management zones. In total, 691 transects yielded 36,791 juvenile fishes from 120 species over the three recruitment years providing an average of 53 individuals (± 2.6se) 30m^{-2} transect or 1.8m^{-2}. However, recruitment rates were far from uniform in time or space. There were stark differences in abundance between years (Figure 1a). Transect abundance means in 2009 were 82 (±6.3se), 19 (±1.2se) in 2010 and 77 (±4.6se) in 2011. Remarkably this 75% drop in abundance in 2010 coincided with a small increase in mean species richness.

Fish recruitment patterns in space were censused at a number of different spatial levels including between locations, reef zones (back reef versus lagoon) and management zones (sanctuary versus recreational). Abundance means among the 20 locations were quite variable ranging from 111 recruits $30m^{-2}$ at Elle's back reef to just 10 at the Coral Bay south location. Overall, mean recruitment was strongest in the southern section of NMP (Cloates to 3-Mile Camp) than at either the eastern (Bundegi) or northern sections (Jurabi to Norwegian Bay). Mean species richness mirrored abundance trends with the southern sections recording richer species diversity than either eastern or northern sections.

Abundances at reef zones varied considerably in years where recruitment was strong (2009 & 2011) but varied little in 2010 when recruitment strength was 25% that of 2009 & 2011 (Figure 1a). Overall, back reef sites contained higher mean abundances than lagoon sites with 67 (±4.0se) individuals 30m-2 transect and lagoonal sites 35 (±3.0se). For species richness, trends were more variable but generally back reef and lagoonal sites held similar mean numbers of species ranging from 14.1 species in the 2010 lagoon samples to 5.5 in the 2011 lagoon samples with back reefs somewhere in between (Figure 1b). Of note, species richness at both back reef and lagoonal sites was highest in 2010 when abundances were lowest indicating that species richness is unlikely to be affected by recruitment strength (i.e. numbers of individuals).

These patterns were similarly replicated at management zones. Sanctuary zones generally recorded marginally higher mean abundances and species richness than recreational zones in the strong recruitment years of 2009 and 2011 but were quite similar in 2010. On average across all years, sanctuary zones contained 59.7 (±4.1se) individuals and 10 (±0.29se) species and recreational zones 44.1 (±2.8se) and 8.9 (±0.33se) respectively.

Taxonomic trends in recruitment revealed the strong dominance of the Damselfishes and Wrasses in both back reef and lagoon reef zones. Other important families to both reef zones included the Parrot and Cardinal fishes. In spite of the ubiquity of these groups dominating patterns at the family level, there were many species that were unique to either back reef or lagoon reef zones. Of the 120 species recorded during the study, 19 species were uniquely found in the lagoon and 16 unique to back reef sites with 68 having some margin of overlap. The remaining 17 species were considered to be nominal reef zone specialists because of their low numbers. Importantly, the recreationally targeted Emperors and functionally important Goat and Rabbitfishes were exclusively found at lagoonal sites foraging amongst the large Sargassum algae stands that dominate the lagoon during the summer recruitment season. Percentage contributions from families varied considerably from year to year. For example, the Rabbitfishes were almost entirely absent in 2009 and 2010 (<0.1%) but made up 19% of recruits in the lagoon in 2011. Similarly, the Wrasses constituted 17% of the overall recruit assemblage on the back reef in 2009 but 34% in 2010 illustrating the variability in taxonomic composition in both space and time.



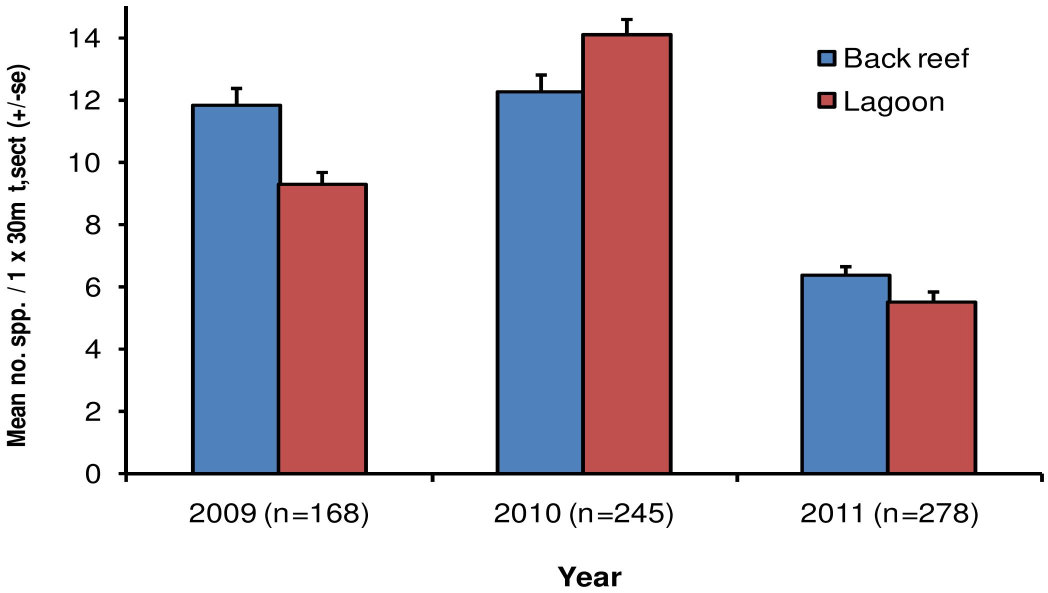


Figure 1a-b: Mean abundance and species richness among reef zones and the three years of study showing the degree of recruitment variability.

Management Implications

This study provides valuable baseline information on the recruitment characteristics and trends of fish at NMP through time and space. The overarching message is that there is a large degree of natural variability associated with recruitment at NMP, a pattern that is common to coral reef systems throughout the world. Marked differences were found between years, locations, reef zones, management zones and taxonomic composition. Although this general finding lacks a specific management alarm-signaling threshold (i.e whether a significant change is cause for concern), a closer look highlights a number of Key Findings that have important implications to the way in which monitoring and research for management is directed. Moreover, this study has developed, tested and fine-tuned techniques for assessing fish recruitment that are simple, clear and Ningaloo-specific. This includes the timing of annual data collection, best practice methodologies and protocols, establishment of permanent monitoring sites, the identification of sources of potential observer and methodological error and how to avoid or minimise these. In addition, there is now a comprehensive three year data set for fish recruitment.

The identification of commercially and functionally important fish species that recruit solely to either back reef, coral dominated <u>or</u> algal dominated lagoonal areas cannot be overstated. This finding has obvious implications for the need to ensure that both habitat areas are adequately represented in the zoning scheme to support recruitment and maintain the health of the coral reef system.

Another important finding is the increased abundances of fish recruits to sanctuary zones. Whether this is a function of sanctuary zones having originally been chosen on the basis of maximum habitat complexity (i.e. more structurally complex habitats tend to be more diverse and aesthetically pleasing) or some other more complex ecological reason (e.g. trophic cascades) remains unresolved. However, quantitative data confirming the appropriateness of sanctuary zone positioning and its effects on maintaining biodiversity has its obvious advantages to adaptive management goals.

The answers to management questions posed for this project can be summarized briefly, with further detailed explanation in the Key Findings above:

What is the current levels of fish recruitment? Recruitment at NMP, like elsewhere in the world, is highly variable through both time and space. The range at Ningaloo was anywhere between 23 and 111 juvenile recruits and we witnessed a 75% drop in abundance in 2010. These figures put fish recruitment in the low to medium range overall.

How does this compare with other comparable reef systems? Fish recruitment is comparable to that in other global locations. Having said this, recruitment ranges within specific reef systems themselves are extremely plastic due to the high natural variability inherent in the process making reliance on direct comparisons difficult. The generation of a long-term, system-specific, recruitment dataset is likely to be more useful than direct comparisons among disparate locations because of the unique set of oceanographic, geomorphological and biotic conditions found within each system.

What cost-effective methods should be used for long-term monitoring of fish recruitment? Fish recruitment can best be measured using 30 x 1m transects at key locations within back reef and lagoon habitats. It is strongly advised that annual censuses of both groups be continued so that a long-term, system-specific dataset can be recorded. Only in this way can patterns of recruitment and the causative factors for variation be assessed and management strategies directed towards the maintenance or enhancement of larval input. Finally, it should be noted that it is unlikely management can directly influence larval input into Ningaloo. Instead, the best tactic is a preventative one in which the health of reproductive adults and the general well-being of the ecosystem is the first priority.

Are current management strategies, including zoning, appropriate to maintain acceptable levels of coral and fish recruitment? This is a very difficult question to which there is no definitive answer at present. Fish recruitment levels, although highly variable, appear at natural levels and are adequate to maintain the health of the system as it now stands. Once again, the continuation of annual recruitment monitoring is key to answering this question and should be a priority for management. By recording recruitment and comparing future levels of ecosystem and general adult fish abundance and health, a comparative assessment could certainly be made with some level of confidence.

Acknowledgements

We would like to thank Frazer McGregor and Mike van Keulen from the Coral Bay Research Station, the owners of Ningaloo, Warroora & Gnaraloo Stations and the team at the DEC regional office in Exmouth who provided invaluable information and on field work logistics.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Datasets and formats:

- 2009-2010 Fish recruitment database (Microsoft Access .accdb)
- WayPoint file of fish recruitment site locations (.wpt)
- Juvenile fish field identification sheets (Microsoft Word .doc)

Access to these files is managed and available through AIMS.

Knowledge transfer

This is a Baseline and Process project on an ecological asset of the marine park. Its main application will be to the design of cost-effective monitoring protocols for key ecosystem processes. It also provides some initial baseline information for the long term monitoring program.

6.5 Project 3.1.2: Methods of monitoring the health of benthic communities - coral recruitment.

Principle Investigator
Martial Depczynski, Andrew Heyward (AIMS)

Research Team
Martial Depczynski, Mark Case, Jamie Colquhoun, Tim Cooper, Andrew Heyward, Rebecca O'Leary, Ben Radford, Paul Tinkler (AIMS), Shaun Wilson, Thomas Holmes, James Moore (DEC)

Project Overview
Effective ecosystem management relies on continually assessing trends and changes in resident organisms (i.e. adaptive evidence-based management). Of particular importance are those organism groups that serve vital roles and functions within these ecosystems. Corals and fish are perhaps the most visually conspicuous and critical ecological components of coral reef ecosystems. Together, they provide essential habitat and perform a host of important tasks that maintain the health and integrity of these systems. Intricately linked to coral reef food webs, these organisms have significant value in generating, storing and providing energy within reef ecosystems. Given the importance of these roles and the responsibility of managers to maintain the health of these systems, it is vitally important that changes in these organisms are detectable. However, without a historical backdrop of baseline information, it is impossible to determine whether changes in these parameters are due to natural variability or are cause for concern.

At the core of marine biodiversity and ecosystem maintenance is the annual replenishment of individuals (i.e. Recruitment). Most marine organisms have a bipartite life cycle where larvae recruit into their juvenile and adult habitat from the open ocean. For coral reef ecosystems, annual recruitment is concentrated over just a few months of the year for most fish and coral species. Conveniently, this also provides a metric by which we can measure the potential success of an ecosystem on an annual basis allowing us to forecast into the future and begin to understand the properties that govern replenishment patterns at local scales. For this information to be useful though, baseline information on abundance, species identity and structure across space and time is required to be able to differentiate between natural variability and changing trends.

Objectives
This project had two main aims:

- Design parameters and protocols for a long-term monitoring program of coral communities in NMP including; baseline data, coral recruitment relationships and the required levels of spatial and temporal replication; and
- Develop a better understanding and assess the effectiveness of management zones (i.e. sanctuary versus non-sanctuary) in supporting recruitment.

In order to achieve these objectives this study set out to provide baseline data on current levels of coral recruitment using a variety of methods and to establish coral recruitment monitoring sites at an appropriate spatial and temporal scale.

This study measured annual coral recruitment using terracotta tiles deployed by divers on the reef onto permanent tile mounting fixtures that were then subsequently retrieved and counted under a dissecting microscope. As a basis of comparison, techniques for established juvenile corals were also employed including diver based visual census (UVC) and a variety of camera methods. Full details on the methods employed in this research can be found in Depczynski et. Al. (2011).

Key Findings

Measures of newly settled corals following the 2009 and 2010 annual coral spawning peaks in the northern half of NMP recorded an annual influx of coral recruits at all locations. Recruitment rates spanned the range recorded for coral reefs elsewhere, with overall average numbers of recruits per tile in the medium range, but a few locations high and many locations low-medium relative to other similar Indo-Pacific studies. There was spatial and temporal variation in recruitment levels and taxonomic composition over the two annual cycles (Figure 1).

In 2009 a total of 1999 recruits were counted, dominated by species in the family Acroporidae. In 2010 a total of 841 recruits were counted, a drop of 58% from the previous year, due largely to a drop in Acroporid recruits, with other taxa represented in similar levels between the two years. This result most likely reflects normal inter-annual variation in larval output, reduced larval production by the Acroporidae due to some selective stress effect during the preceding year, or a sampling artifact. Some degree of sampling artifact is plausible as 2010 saw a split coral spawning period, with significant Acroporid spawning one month earlier than the major spawning peak of most other species. In any long-term monitoring of recruitment at NMP approximately 50% of years will include a significant split spawning in the period between late February and early April. This should be factored into the future sampling designs.

Spatial scales of kilometers, between sites within a region of NMP, had the greatest effect on variability in the recruit data, followed by larger scale location differences between regions (Tantabiddi, Bundegi and Coral Bay). Within each study site, at scales of 50-100m and between groups of replicate tiles separated by only a few meters, variability in recruitment counts was generally much less, although there was typically a poor correlation between the abundance of live coral over the 100m site scale and the number of recruits. A more representative program of tile-based sampling could be achieved with the same resources by placing, for example, 6-10 tiles at each site rather than 18 in three groups of six, but establishing twice the number of sites within a few kilometers of each other.

The results suggest that recruits are being drawn from stocks of spawning corals at a larger scale than the immediate vicinity of the recruitment tiles and this relationship is not well established for NMP. However, new datasets, such as the hyperspectral derived coral habitat maps (Cluster 1.2), along with improved fine scale circulations models for NMP (project 3.5.1), could be used to develop predictive models elucidating the size of spawning coral stocks. This would allow a robust test of the stock-recruitment relationships in different areas along NMP.

This study also had a particular focus on evaluating some alternative methods for juvenile coral census, in particular understanding the tradeoffs associated with simplified and more cost-effective approaches. This was addressed through assessing methods that could still yield robust research data, yet utilize non-specialist regional DEC staff for routine field surveys, maximizing the effectiveness of Perth-based specialist research staff for more complex analytical tasks. Methods assessed include tiles to record early recruitment and UVC census and camera-based methods to record juvenile recruitment.

Tiles proved useful to confirm larval supply and early recruitment, but do require use of SCUBA divers and laboratory analysis with microscopes. The deployment and recovery of tiles also require coordination in relation to annual spawning cycles and significant field effort, although deployments to bracket the entire spawning period, for example, deployment in early-mid February each year and recovery late April-early May, would simplify logistics. Nonetheless, resource demands with this method are moderate to high in both field and laboratory and may not be easily met by regional staff. Additionally, given the spatial and interannual variability detected in this study, there needs to be an extension of this data set over more years before the level of covariance can be fully characterized and allow for reduction of sites to a minimum number of sentinel locations.

Census of established juvenile corals, typically 6-12 months or older, using diver-based visual census or a variety of camera methods can provide an alternative to tiles. Both these methods assess the size of juvenile cohorts recruiting into the adult populations, in particular after the probably high mortality phase that occurs in the months after settlement, as opposed to using recruitment tiles which record a sample of newly arriving and settling coral larvae. The study explored each approach to elaborate the pros and cons in terms of resource demands and data quality.

Similar to other studies, results show that UVC, if applied consistently by well trained and calibrated observers, will reliably detect as many or more of the smallest juvenile corals in most habitats. However, it requires significant underwater field time, expertise in coral identification and, in nearly all environments, the use of SCUBA. There is much less difference between UVC and imaging methods for medium to larger juvenile corals and in some habitat types photos may be more effective at detecting encrusting forms. Photos have a number of advantages over UVC in that they appear to allow for more objective assessment of the general benthos and detection of more species, especially encrusting forms, than divers trying to do a rapid UVC. Secondly, provided standard field protocols for camera types, setting and use underwater are followed, non-technical staff could collect photo quadrats to an acceptable standard and these could be dispatched electronically to head office to allow specialist interpretation. In this way a core group of highly trained specialists could produce reliable data while not being required to undertake all regional field work.

For size measurements from photos some form of image calibration is required. In this study a negatively buoyant quadrat frame was deployed and photographed on the seabed. This provides excellent calibration of the image and subsequently the dimensions of all visible small corals. However it does require the diver to carry extra equipment and involves multiple steps deploying the quadrat or other scale reference, photographing the seabed ensuring it is in the frame, then recovering the reference scale before moving to a new sampling location and repeating. It would be desirable to simplify this protocol as much as possible, particularly if shallow surveys in lagoonal habitats are to be surveyed using snorkel divers rather than SCUBA.

As a whole, in most environments divers will detect more of the smallest juveniles, but the time taken to get the best results and the level of diver knowledge and training will be significant factors in the reliability of collected data in situ. These considerations therefore favour alternative approaches, such as the use of cameras with standard, simplified protocols, if non-specialist regional staff are to be used as part of routine recruitment monitoring programs. A robust, spatially and temporally extensive monitoring program is likely best served by use of specialist field methods (tiles, UVC) in a targeted way at selected regional sites, which provide robust calibration data for a more extensive and regular collection of calibrated photographic surveys by generalist staff.

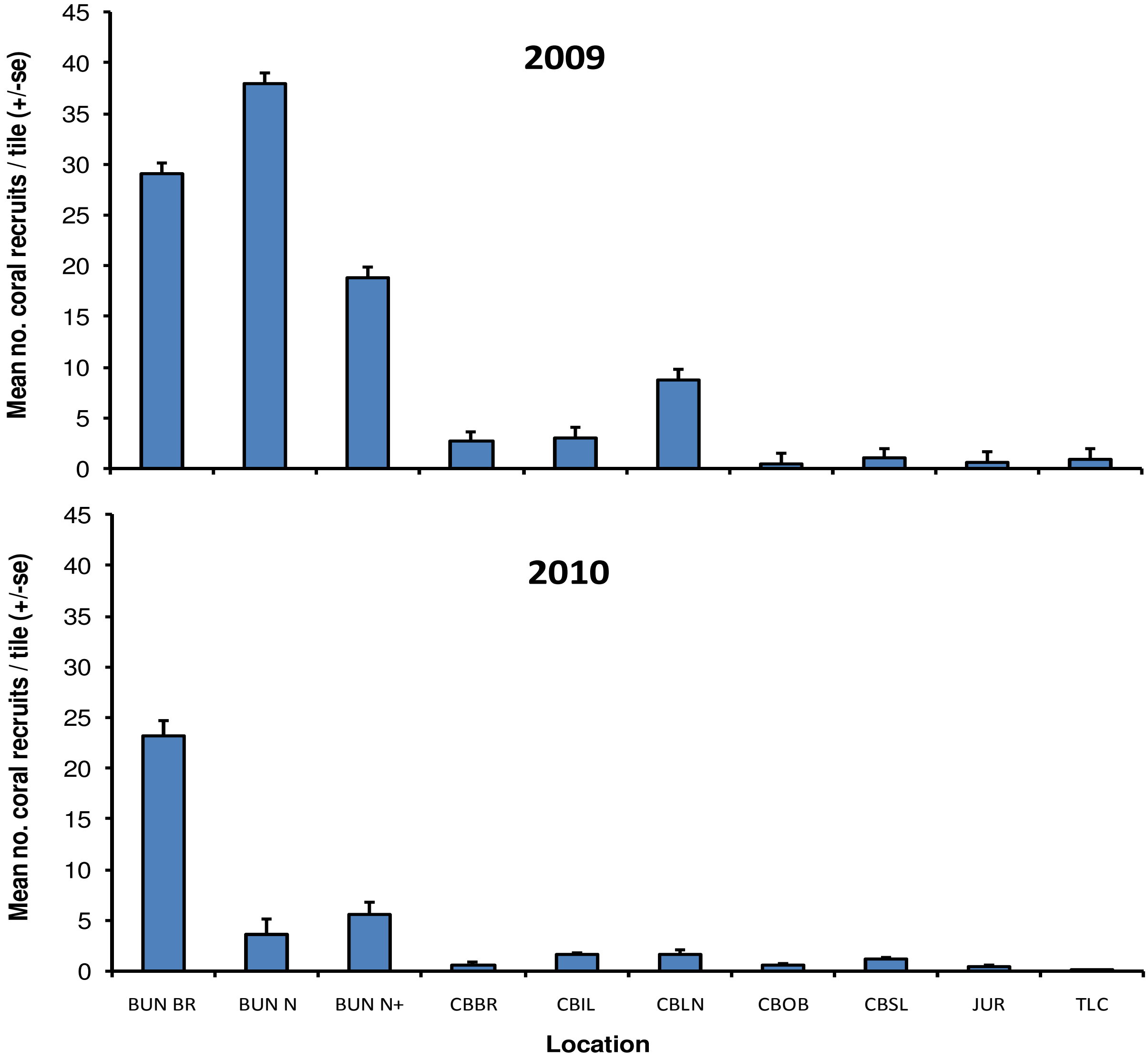

Figure 1: Mean coral recruitment per tile among locations in 2009 and 2010 indicates the variability associated with coral recruitment patterns through time and space. Mean recruitment was much lower in 2010 and was largely attributable to lower recruitment of the family Acroporidae. Location prefixes: BUN = Bundegi, CB = Coral Bay, JUR = Jurabi, T = Tantabiddi. Suffixes refer to specific sites within these areas.

Management Implications

This study provides valuable baseline information on the recruitment characteristics and trends of corals at NMP through time and space. The overarching message from this study is that there is a large degree of natural variability associated with recruitment at NMP, a pattern that is common to coral reef systems throughout the world. There were marked differences between years, locations, reef zones, management zones and taxonomic composition. Although this general finding lacks a specific management alarm-signaling threshold (i.e whether a significant change is cause for concern), a closer look highlights a number of Key Findings that have important implications to the way in which monitoring and research for management is directed. Moreover, this study has developed, tested and fine-tuned a range of techniques for assessing coral recruitment that are simple, clear and NMP-specific. This includes the timing of annual data collection, best practice methodologies and protocols, establishment of permanent monitoring sites, the identification of sources of potential observer and methodological error and how to avoid or minimise these. In addition, there is now a comprehensive two year data set for coral recruitment.

Large spatial variation in recruitment was noted between sites. Further spatial and temporal characterization of larval supply is recommended in order to ultimately select a subset of cost-effective sentinel sites where labour intensive specialist survey methods are utilized. Additional investigation into the scale of coral stock recruitment coupling is also desirable in order to predict the spatial extent of localized, ecological scale connectivity. The recently updated habitat mapping models derived for the NMP hyperspectral database, combined with the latest fine scale circulation models should provide insights into locations where abundant coral and localized return eddy's combine to ensure maximal recruitment on a regular basis, (e.g. Bundegi, versus locations which rely on more transient or widely dispersed larval sources and which may therefore be strongly affected by annual local weather conditions etc).

Consumer grade digital cameras and underwater housings provided an effective tool for detecting juvenile corals in many reef environments, particularly in less topographically complex habitats and for corals that are above 2-3cm in diameter. Consequently cameras are reliable for inter-annual repeated measures at specific locations, but may not be reliable tools for detecting small cryptic corals, especially in moderately or highly topographically complex habitats. The result means that camera surveys will provide a useful measure of multi-year trends and the abundance of corals mostly beyond one year old, but not young-of-the-year cohorts. Nor will they be able to detect changes in post-recruitment survival during the first 12 months of life. Those questions will require a combination of recruitment tiles, diver UVC and camera photo sampling to resolve process related questions that may be influencing the ultimate survival of small corals at particular locations.

There are very recent technical developments with off the shelf consumer 3D cameras that may improve the in-water efficiency of gathering spatially calibrated imagery. A preliminary analysis of one retail example for which an underwater housing is also available, the Fuji W3 3D camera with RecSea housing, indicates that when taking images from a nominal distance of 60cm and at various angles, the errors in precision of target measurements are always less than 10% and typically much less (see Appendix). This level of precision is more than adequate for assigning juvenile corals to annual size classes. These types of camera system warrant further assessment as they may provide a very simple method to deliver high quality fully calibrated images in a single step and with minimal training for field users. Such images may then be transmitted to specialist staff for classification and measurement of the benthos, including juvenile corals.

The use of cameras, not withstanding the above described limitations, should permit acquisition of useful field data over time to monitor coral juvenile abundance by generalist field staff. GPS located transects may be surveyed simply, following a documented camera use protocol, and the resulting photos transmitted to the core marine research specialist for interpretation. Rules associated with image interpretation and reference images should be established to maximize inter-observer consistency.

The answers to management questions posed for this project can be summarized briefly, with further detailed explanation in the Key Findings above:

What are the current levels of coral recruitment? Recruitment at NMP, like elsewhere in the world, is highly variable through both time and space. For corals, 4-10 recruits per tile were found and there was also a 58% drop in abundance in 2010. These figures put recruitment for corals in the low to medium range overall.

How does this compare with other comparable reef systems? Coral recruitment is comparable to that in other global locations. Having said this, recruitment ranges within specific reef systems themselves are extremely plastic due to the high natural variability inherent in the process making reliance on direct comparisons difficult. The generation of a long-term, system-specific, recruitment dataset is likely to be more useful than direct comparisons among disparate locations because of the unique set of oceanographic, geomorphological and biotic conditions found within each system.

W*hat cost-effective methods should be used for long-term monitoring of these factors (including indicator species / groups, temporal and spatial scales)?* A number of methodologies to assess coral recruitment have been presented that target different life-history stages, either larval supply through recruitment tile deployment at key locations or juvenile censusing via a number of observer or photo-based methods. Because the choice of technique is heavily dependent on the objectives of particular studies, field time allocation, degree of expertise, budget and post-processing resources, future workers are strongly urged to measure up the pros and cons of each technique before adopting one or more approach. It is strongly advised that annual censuses be continued so that a long-term, system-specific data-set can be recorded. Only in this way can patterns of recruitment and the causative factors for variation be assessed and management strategies directed towards the maintenance or enhancement of larval input. Finally, it should be noted that it is unlikely management can directly influence larval input into Ningaloo. Instead, the best tactic is a preventative one in which the health of reproductive adults and the general well-being of the ecosystem is the first priority.

Are current management strategies appropriate to maintain acceptable levels of coral and fish recruitment? This is a very difficult question to which there is no concrete answer at present. Coral recruitment levels, although highly variable, are natural and adequate to maintain the health of the system as it now stands. Once again, the continuation of annual recruitment monitoring is key to answering this question and should be a priority for management. By recording recruitment and comparing future levels of ecosystem and general adult coral and fish abundance and health, a comparative assessment could certainly be made with some level of confidence.

Acknowledgements
We would like to thank Frazer McGregor and Mike van Keulen from the Coral Bay Research Station, the owners of Ningaloo, Warroora & Gnaraloo Stations and the team at the DEC regional office in Exmouth who provided invaluable information and on field work logistics.

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Wilson, SK, Depczynski M, Fisher R, Holmes TH, O'Leary RA, Tinkler P. 2010. Habitat associations of juvenile fish at NMPReef, Western Australia: the importance of coral and algae. PloS One 5 (12): e15185. Doi:10.1371/journal.pone.0015185

Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Datasets and formats available on baseline coral recruitment information include:

1) 2009-2010 Coral settlement tile database (Microsoft Excel .xlsx)
2) WayPoint file of coral settlement tile site locations (.wpt)
3) 2009-2010 UVC data (Microsoft Excel .xlsx)
4) Raw image collections (.jpg)

Accesses to these files are managed and available through AIMS.

Knowledge transfer

This is a Baseline and Process project on an ecological asset of the marine park. While it has relevant application through education, research and monitoring strategies, its main application should be to assist in developing and designing cost-effective monitoring protocols for this key ecosystem process. It will also provide some initial baseline data for this monitoring program.

6.6 Project 3.1.3: Stock assessment of target invertebrates (rock lobster and octopus) in the lagoons of NMP.

Principal Investigator
Martial Depczynski, (AIMS)

Research Team
Andrew Heyward, Ben Radford, Rebecca O'Leary (AIMS), Russ Babcock, Mick Haywood, Damian Thomson (CSIRO Marine and Atmospheric Research)

Project Overview
There are two species groups of invertebrates that have historically been intensively taken in NMP: lobster and octopus. Each plays an important role in the marine ecosystem, however little information is available on species distribution, abundance and their capacity to respond to human pressures (particularly fishing). Managing the sustainability of marine invertebrate populations that have been and continue to be extracted from NMP requires some baseline assessment of abundance and spatial distribution of the targeted organisms.

Lobsters are considered to be an important biotic component on coral reefs and are an integral part of the food webs of coral reef systems (Tarr et al. 1996, Shears & Babcock 2002, Langlois et al. 2005). Sitting at the apex of the detrital food chain and at the base of the consumer one, healthy lobster populations are likely to play important roles in the cycling of energy and materials through the NMP ecosystem. Any impacts on the integrity of these stocks may impact on the health of the NMP's ecosystem and the way it operates at a functional level.

Lobster exploitation at NMP dates back to 1933 (Halkyard 2005) and a commercial industry based on the extraction of western rock lobster operated from the 1960's to the late 1980's when it became uneconomical due to reduced catch size. Since the gazettal of NMP in 1987, commercial fishing for rock lobster is no longer permitted within the marine park and recreational fishing for rock lobster is only permitted in general use and recreation zones according to the recreational fishing rules for rock lobster as stipulated by Department of Fisheries, WA (DoF)[10]. However, no assessment of the current population status and its recovery to natural population levels has been undertaken prior to this time.

Octopi have a global distribution and have been quite successful colonisers of coral reef ecosystems playing an important role as both predator and prey. The species of octopus most commonly known to occur in NMP, and the principle subject of this study, is *Octopus cyanea, a* widely distributed Indo-West Pacific tropical octopus (Norman 2000) that have been reported to grow up to to 9kg (Guard & Mgaya 2002). In NMP octopus are readily fished in the inter-tidal shoreline areas and, although occasionally taken for food, are primarily hunted by recreational finfish fishers for bait. Similar to the lobsters in the NMP, there is currently no information on their numbers, diversity, patterns of distribution or consequent vulnerability to exploitation. Further, there are no regulations protecting this species group within NMP, other than the bag limit of 15.

[10] This includes fishing seasons, legal size limits and a bag limit of 4 lobster per person per day (8 per boat) within NMP.

Objective

This study was undertaken to assess current abundance estimates and distribution of lobster and octopus, along the length of the NMP. It also sought to place today's population estimates into an historical framework and will provide relevant information on lobster and octopus response to human pressure needed to inform management decisions and actions. In particular, this research, alongside that of Project 3.2.2d provides the first quantitative estimate of lobster and octopus populations along the Ningaloo coast.

Materials and Methods

Lobster

Underwater visual census (UVC) was used at inner and outer reef sites within both recreational and sanctuary zones (SZ) from Lighthouse SZ in the north to Turtle SZ at the southern end of NMP to identify and count individual lobsters. In total, 265 transects encompassing 58 sites at 17 separate locations were undertaken in May, July and September 2008 (Figure 1). Habitat data was also collected *in situ* for each transect in order to correlate lobster numbers to habitat type for each lobster species found. In addition, interviews were undertaken with individuals previously involved in the commercial lobster fishing industry in NMP to provide some historical context for population distribution and abundance.

Octopus

A number of different designs of octopus traps, including designs considered commercially effective on temperate species near Perth (run by the Fremantle Octopus Company), were initially tested however, this technique was abandoned following the failure of traps to catch octopus. Direct sub- and inter-tidal visual surveys were selected as more appropriate to the tropical reef environment. Sub-tidal surveys on snorkel and SCUBA proved more successful and were done simultaneously with lobster surveys (see above). Additional inter-tidal surveys were conducted in December 2008 providing total coverage of octopus habitat across a reef profile.

Further detail is provided in Depczynski et al (2009) on project methodology and findings.

Key Findings

Lobster

In all, a total of 132 lobster from five different species (1 temperate and 4 tropical) were counted from 265 transects along the shoreline, lagoon and reef slope of NMP (Figure 1). The most common species found was the temperate Western Rock Lobster *Panulirus cygnus* (75) followed by the tropical lobsters - *P. versicolor* (37) and *P. ornatus* (15), with the Spiny Lobster - *P. femoristriga* (4) and *P. penicillatus* (1) also being present (Figure 2a-e). Mean numbers of individuals between the Northern, Central and Southern sections of NMP differed considerably. Over 47% of all observed lobsters were found in centrally located Bateman's Bay and Cloates area at inner reef/sanctuary zone locations, marking it as an obvious hotspot for lobster in NMP (mainly Western Rock Lobster). Overall, there was a general decline in numbers moving southward through the park, with the exclusion of the relatively high abundance in the Cloates sanctuary area.

The temperate and tropical influences in NMP were evident by the presence of species typical of both environments. Further, this study provided additional evidence of the environmental change that occurs throughout the length of the park as the tropical species (i.e. *P. versicolor* and *P. ornatus*) most commonly occurred in the northern end of NMP while the temperate species (*P. cygnus*) dominated in the central and southern areas.

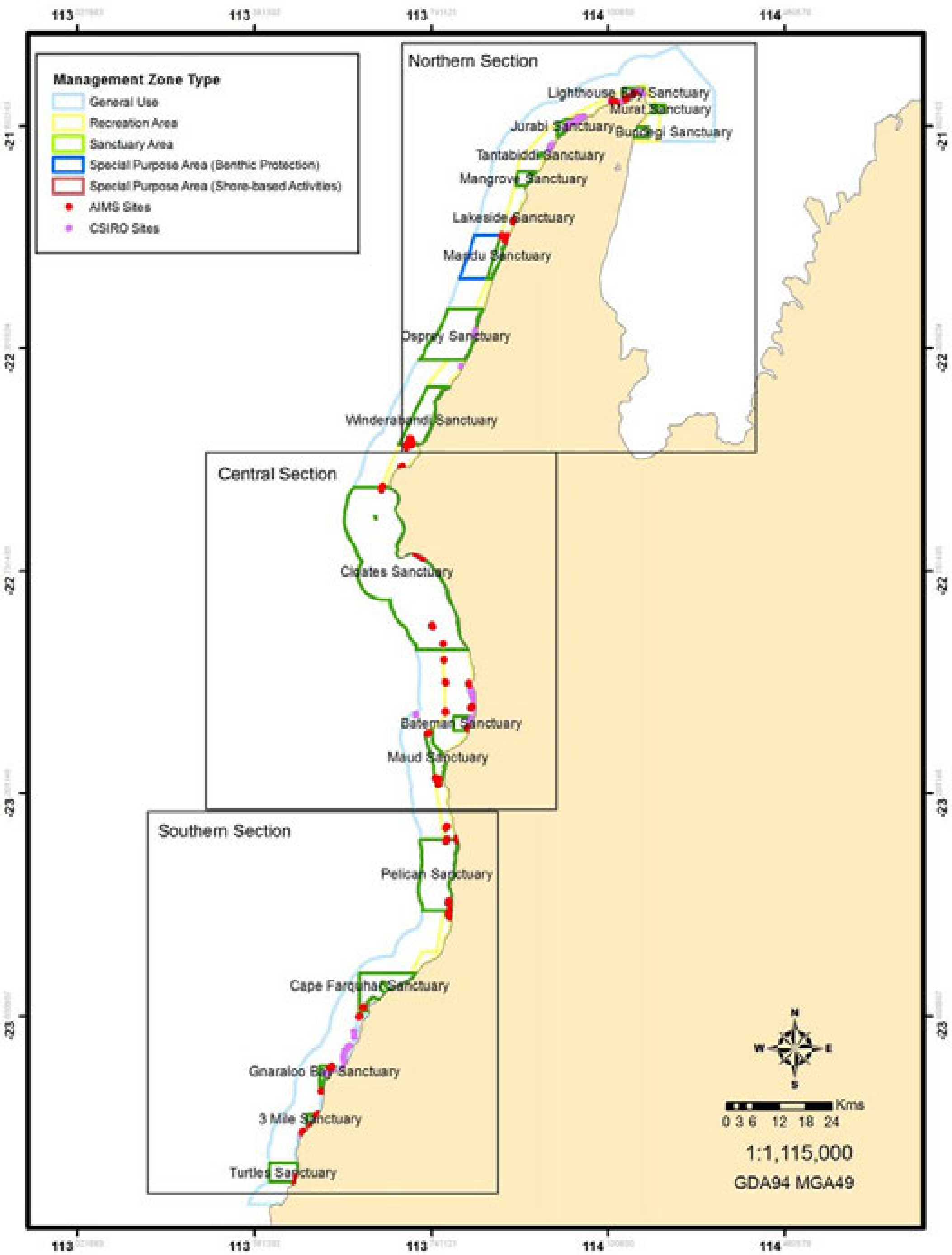

Figure 1: Sampling sites for lobster and octopus throughout NMP.

Some trends were found in habitat characteristics which, given the low number of lobsters and their patchy distribution may be important in understanding their distribution. The Western rock lobster was most often found in sea grass/macroalgal and boulder/reef ledge habitat, particularly in inner lagoon sites. In contrast, the tropical lobster *P. versicolor* favoured outer slope sites with bommies and hard plate corals. All other species did not appear to have well defined habitat preferences however their small numbers preclude effective analysis.

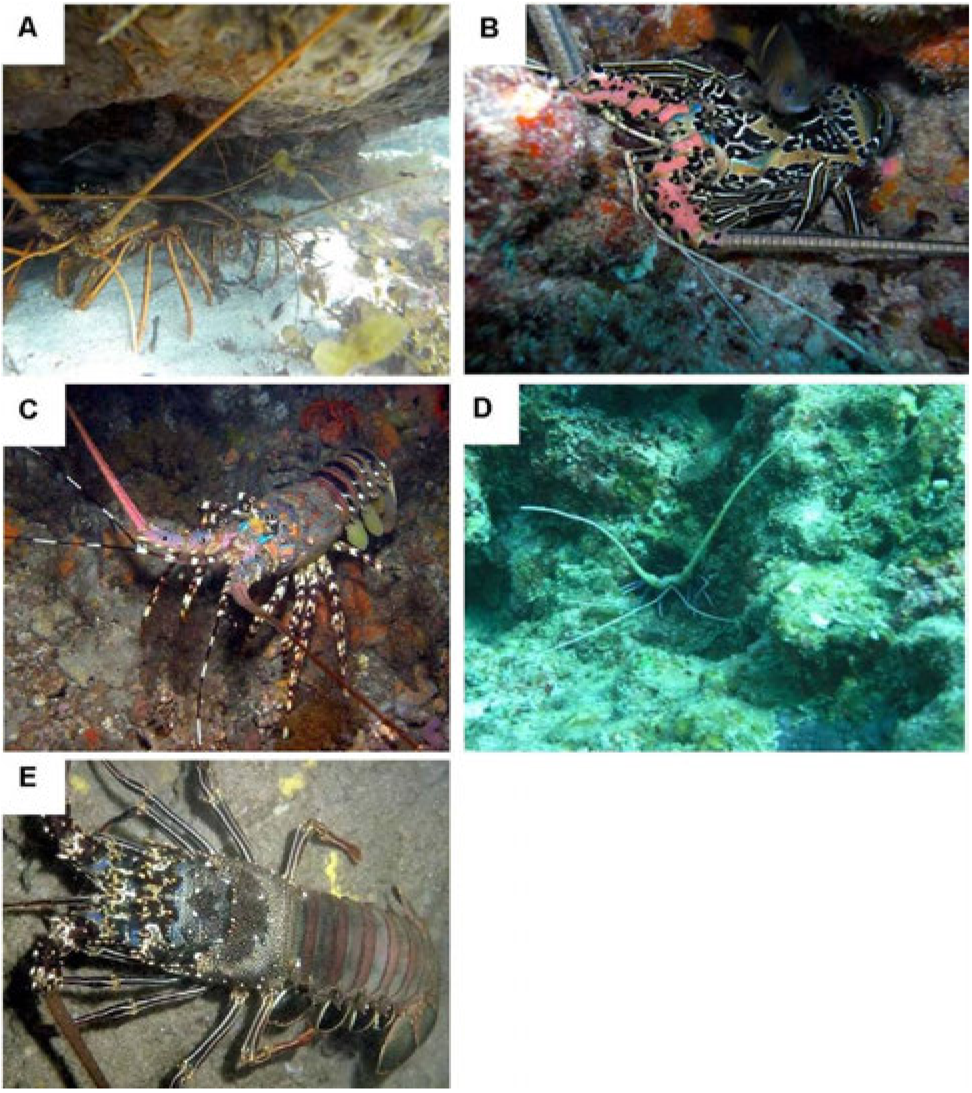

Figure 2a-e: Images taken in situ of the rock lobster species censused along the Ningaloo coastline; a) Western Rock Lobster - *Panulirus cygnus* (total n = 75), b) Painted rock lobster – *P. versicolor* (total n = 37), c) Painted cray – *P. ornatus* (total n = 15), d) *P. femoristriga* (total n = 4) and e) *P. penicillatus* (total n = 1).

Some interesting trends were noted when looking at lobster distribution and abundance relative to human pressures. Namely, lobster numbers are currently low in areas where there are many access points to the beach. Consideration was given as to why rock lobster density at Cloates is an order of magnitude greater than elsewhere within the park. This location is in the middle of the largest sanctuary zone in NMP and one that has been in place since 1989. Further, the area is reasonably remote with limited access via Ningaloo Station. Habitat characteristics in the area are ideal for Western Rock Lobster (limestone ledge, algal and sea grass dominated). Finally, the oceanographic characteristics of the Cloates area may enhance or facilitate juvenile retention and larval recruitment. Here the northward flowing Ningaloo Current hits Point Cloates creating small anti-clockwise eddies in summer when southerly winds predominate (Woo et al. 2006). Together these factors may have helped support the remnants of the Western rock lobster population and any future monitoring should have this area as its centrepiece. Not only does it contain reasonable densities and associated statistical power, but it allows for natural populations to be assessed without the confounding effect of human pressure.

Based on anecdotal information gathered from discussions with individuals involved in the commercial lobster fishery when it operated, it is likely that in the 1960's lobster catches reflected a maximum density of up to 3.3 lobsters m^{-2} (or over 3300 lobsters per ha) in optimal reef habitat. Commercial daily catches during this period were estimated at approximately 100kg day^{-1} km^{-2}, with up to 340 kg taken over a 100 m area in one day on at least one occasion. These high levels of lobster abundance provide a start contrast to the low numbers of today.

Overall these results point to four key findings. First, Cloates is an important area for the remaining Western Rock Lobster stocks in NMP. Second, there is a general decline in tropical lobster numbers southwards along the park. Third, all lobster in NMP have a very patchy distribution, even given correlations with habitat such as outer reef and inner lagoons. Finally, sanctuary zones hold significantly higher numbers of lobsters than recreational zones, even when the Cloates Sanctuary zone was removed from the analysis. The Cloates Sanctuary zone population may be helping the remaining small lobster populations in the NMP.

It seems clear that the lobster population of the NMP is much reduced from historical levels. How long the lobster population has been at these low levels is unknown but their apparent loss from many areas of the Park may have already had some impact on the NMP reef ecosystem through a re-adjustment of functional roles among biota.

Octopus

Although at least three species of octopus are known to occur in NMP, only individuals of the most commonly found species, *Octopus cyanea*, were recorded during this study. In total, just 28 individuals from this species were counted from the 410 transects (265 sub-tidal & 145 inter-tidal) along the entire coast of NMP. This suggests a very low density of octopus in NMP, in fact much lower than that found in other tropical reef systems where *O. cyanea* supports a vibrant artisanal fishery (Guard & Mgaya 2002, Humbar et al. 2006). At NMP, octopus distribution was extremely patchy and while most individuals were found in subtidal rather than intertidal areas, the few intertidal sites where octopi were observed had relatively higher densities. Overall octopi were found to occur in very specific habitat, and, this habitat occurs in only a few small areas along NMP. This finding suggests that habitat may be the key limiting factor on the abundance, density and distribution of octopus in NMP.

However, octopi are incredibly cryptic and are difficult to survey even using SCUBA or snorkel. Underwater and fixed length intertidal transects were the source of data for this study. It is unlikely that all individuals present on transects were recorded. Despite this, the information reported in this study can be used to consider relative measures for different sites, reef and management zones and to establish sites and protocols for future research and monitoring.

Given the low abundance and very patchy distribution of octopus in NMP, the fact that they are harvested for bait (from easy access points to intertidal areas), suggests that their population is quite vulnerable to human exploitation. In addition, a student study supported by this project indicated that the peak of reproductive activity coincides with maximum visitation to the NMP (Herwig et al. in review).

During the course of this study, non-compliance with sanctuary and special purpose zones (shore based fishing) was routinely observed including the spearing of octopus at low tide within some sanctuary and special purpose zones. Their ability to withstand harvesting by recreational fishers will be largely determined by their life history features. Attributes such as their rates of population turnover, fecundity and patterns of growth would be instrumental in determining this and should be considered a future and pressing research prerogative.

Management Implications

This project provides the first comprehensive census of NMP's lobster and octopus populations and sheds light on their general ecology, habitat correlates and overall vulnerability to continued anthropogenic impact. The results from this report provide both baseline population information and a blueprint for future research and monitoring (techniques, reference sites and suggested directions). In the case of management agencies, the nature of the results (i.e. very depauperate populations of both lobsters and octopus) are likely to have an impact on the management policy position of DEC and DoF. Specific implications as they relate to the management questions for this project are detailed below.

Diversity and Abundance

Five lobster species and 3 octopus species occur in the NMP, representing both tropical and temperate species, consistent with the location and environment found in the NMP. The abundance of lobster in NMP is very low in comparison with other reef systems and with what is known from historical records. In particular, the Western rock lobster (P. cygnus) population has significantly declined over the last 50 years, most likely in response to intense commercial fishing pressure during the 1960s to the 1980s. Octopus populations are also lower than that expected for a tropical reef system, however there is no historical information on which to base an NMP-specific comparison and the findings in this study must be treated with caution due to the difficulties in surveying octopus.

These findings indicate that populations of these two groups are either not recovering from previous exploitation and/or may not be able to sustain current levels of harvesting. There are a number of factors that may have an influence on species resilience to exploitation. For example, as NMP represents the extremes of the geographic range for both temperate and tropical species of rock lobster, recruitment and survivorship of these species may be sub-optimal making recovery a difficult and long-term process. This needs to be considered carefully for the long-term conservation of these species and addressed accordingly through management of recreational fishing activities within NMP.

While it is difficult to detect or depict a gradient of pressure correlated with such low abundances, there is some evidence that current human pressure (based on accessibility) is affecting the remaining lobster and octopus populations. Further research and monitoring are warranted to determine whether populations can withstand and/or recover based on current status and the level of pressure to which they are exposed. Recommendations for future management in this regard would include:

- Expanding our understanding of lobster recruitment through supporting Fisheries WA puerulus (lobster larvae) collectors in Coral Bay and encourage additional collectors to be placed further north, particularly Jane's Bay just south of Point Cloates; and
- Supporting further investigations on the life history of the main (targeted) octopus species *Octopus cyanea* as a means to understand both their role in the NMP ecosystem and their vulnerability to fishing pressure.

Appropriateness of regulations

Based on the evidence in this study the current regulatory framework, including compliance surveillance, is not sufficient to adequately protect these two taxonomic groups at NMP. For lobster, this may be because populations are living in already sub-optimal conditions, have already been depleted well below a sustainable level and are unable to sufficiently recover from this exploitation. For octopus, the fishing pressure within small intertidal areas where they are often found, the sometimes illegal methods by which they are harvested and the timing of harvesting during the reproductive season casts doubt over their future population viability in NMP. The taking of both of these species may simply be unsustainable within the NMP. At this stage the following management recommendations should be considered to ensure the long-term sustainability of these two groups:

- Close NMP to recreational lobster fishing until the populations recover sufficiently. This would allow further investigations into their potential for recovery;
- Continue monitoring lobster populations, in fished and non-fished (i.e. sanctuary zones) areas;
- Restrict the taking of octopus bait in some currently fished areas to allow a natural population to exist. This would allow a proper assessment of the carrying capacity and regeneration of NMP octopus populations;
- Compliance officers should target illegal harvesting of octopus on reef flats. Techniques used to take octopus also need to be policed and enforced (i.e. illegal “spearing” in designated “Special purpose -shore based fishing zones"). Remote cameras at selected reefs (e.g. Mildura Wreck especially) could be used to establish the extent of the problem and enforce laws.

Monitoring
Given the pressures experienced by both species groups, it is advisable to continue monitoring these species to track any deleterious trends that can be attributed to human activity. If changes to current regulations are to be made as recommended, then monitoring becomes even more critical to assess the effectiveness of changed management regime and determine the recovery of these populations. This study has employed a set of monitoring protocols for both lobster and octopus that were demonstrated to be reasonably effective and produced an initial baseline estimate of population distribution and abundance that can be employed in future monitoring activity. In general it is recommended that monitoring of these populations be continued at selected sites using sensitive indicators such as increases in distribution, inter-annual fluctuations and increased densities at critical sites.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Datasets and formats include a list of lobster and octopus survey locations including GIS reference, count data for each survey undertaken and written interview transcripts with ex-commercial rock lobster fishermen.

Knowledge Transfer

This information will be useful to DEC and DoF in assessing and managing the long-term health of target invertebrate populations at NMP. It is considered a Baseline study on an ecological asset and has application through management frameworks, education, compliance, research and monitoring strategies.

6.7 Project 3.1.4: Local and regional migratory patterns of whale sharks at NMP

Principle Investigator
Mark Meekan (AIMS)

Research Team
Conrad Speed (CDU, AIMS), Corey Bradshaw (CDU, SARDI), Serge Planes (Universite de Perignan), Cary McLean (AIMS)

Project Overview
The whale shark is the largest fish in the world and feeds primarily on plankton. The species is distributed around the world in tropical and warm temperate seas and is known to aggregate in nearshore waters annually in places like NMP and to migrate long distances between times. Whale sharks have a distinctive pattern of light dots and stripes along their body which has enabled the use of photo-identification as a tool to study these animals and determine their migratory pathways, life history parameters and connectivity between populations. However, our current understanding of their movement and connectivity between populations is still very limited. As such, and given the current threat of fishing to them, whale sharks are considered a threatened species and are listed as 'Vulnerable' in Australian State and Commonwealth legislation as well as international bodies (e.g. World Conservation Union).

Whale sharks aggregate in the autumn and early winter months each year at NMP and a tourism industry has been built around this predictable behaviour. Consequently data on whale shark movement and visitation of the reef has been collected over recent years. This project represents an international and ongoing collaboration that is seeking to improve our understanding of the whale shark, its migratory patterns and population linkages across the Indian Ocean. It reviews current monitoring methods and research techniques and highlights protocols and research initiatives that will be useful in answering these questions. WAMSI has contributed to this larger research program seeking scientific rigour around the information on whale sharks that visit NMP, the relative impacts of the ecotourism industry and effectiveness of current management.

Objective
The aim of the research was to characterise whale shark abundance and use of NMP in relation to ecotourism industry through the following Objectives

- Review current monitoring methods and highlight viable data collection and analysis techniques;
- Develop new protocols for genetic analysis to assist in understanding population structure;
- Use photo-identification techniques as a basis for mark-recapture and demographic analysis of population and stock structure at Ningaloo;
- Deploy satellite tags to document migration and diving patterns and compare these to environmental variables; and
- Analyse historical databases of whale shark sightings by ecotourism operators in NMP to determine trends over time and the influence of oceanographic phenomena

Materials and Methods

A range of methods were trialled at NMP to enhance individual identification of whale sharks. Methods were chosen that caused minimal impact to the animal and that did not require physical restraint. This study employed photo-identification, collection of tissue samples (faecal, biopsy, microplane) and deployment of satellite tags (Splash, fin, PSAT). For a fuller description of the methods employed, see Meekan et al (2008).

Key Findings

Whale sharks are found in tropical waters around the world and, while they display broadscale migration patterns, there is little information on the extent of their migratory pathways or where mixing between populations may occur. Genetics has been used to try to identify specific populations and the interchange between populations So far, genetics has shown a lack of population structure for the Indian and Pacific Ocean, indicating that animals are dispersing and mixing across this range, however it is still unclear exactly where animals may be mixing.

Whale sharks are found in most habitats within NMP outside the fringing reef, including in deep offshore waters beyond the marine park. However, they were found to favour the 60m depth contour. This depth coincides with some geomorphological features, namely a series of benthic pinnacles that add complexity to the seafloor habitat and no doubt influence the sea life above, representing a likely concentrated food source. The whale sharks that frequent NMP are mainly juvenile males, whereas large, breeding females are rarely seen. It may be that NMP is suited to these smaller animals as it provides a rich food source via upwelling and plankton blooms supported by the Leeuwin Current that is available without diving to deep colder waters which can be energetically expensive for smaller animals. The diurnal movement patterns of whale sharks in NMP are similar to those of their main food items, i.e. they tend to move offshore at night and aggregate in deeper water.

Whale shark distribution within NMP is mimicked by the ecotourism industry which focuses its activities in inshore waters (<100m). The major overlap between whale sharks and tour boats is between depths of 15 to 60m, where whale sharks are most commonly found inside NMP.

Individuals tagged in this study were found to travel up to 1000 km from NMP, to waters near Indonesia, Timor and Christmas Island. Interestingly, photo-identification studies have not found matches between populations that frequent different localities (e.g. Mozambique, Seychelles, Ningaloo, Philippines) suggesting that there are no links among these distant Indian Ocean populations. However, genetic studies have shown whale shark populations to be fairly homogonous at this scale, suggesting some degree of connectivity.

Approximately 30-60% of whale sharks photographed in these catalogues have evidence of boat strike injuries, indicating that collision with vessels may be an important cause of mortality for this species.

There is evidence from this study that the whale shark population that visits NMP is declining in size and age. As noted above, it is mainly juvenile males that visit Ningaloo and there is evidence that the average size and abundance of older, larger males has been declining over the past decades.

A variety of techniques were trialled through this research to further our understanding of population parameters and distribution including photo-identification, satellite tagging and genetic sampling and analysis. Photo identification has proved a useful tool in exploring population abundance through mark recapture, population demographics such as survival and assessing anthropogenic threats such as boat strike. Development of microsatellite markers for genetic tagging proved to be a far greater technical challenge than was originally anticipated and took 24 months to complete. A full library of markers is now available and work has commenced on collating and processing genetic samples from NMP and other Indian Ocean populations.

Management Implications

The whale sharks that visit NMP are part of an Indian Ocean population that travel far beyond the boundaries of WA, and Australian waters, thus there is a need for international as well as regional approaches to the management and conservation of this species. Whale sharks face several human related pressures in international and other jurisdiction waters, namely fishing and boat strike, however it is difficult to quantify these pressures given the lack of information on migratory patterns and life history. The results of this research suggest that ecological connectivity is quite low so that, on shorter time scales, there is little interchange between populations across the Indian Ocean. However, individuals from the NMP population have been recorded travelling as far as Indonesia and Timor, indicating that the NMP population of sharks is part of a wider Indian Ocean stock that is likely to encompass much of the south eastern Indian Ocean and the waters of South East Asia. Thus management at a regional level (i.e. between Australia and Indonesia) will have real and valuable outcomes for the whale sharks that visit NMP.

It is still equally important to consider the management of this species across its entire range and life cycle. This means that knowledge gained of whale shark presence, behavioural and population dynamics in WA waters should be shared with international researchers and managers and collaborative or supportive management strategies employed where possible. In terms of management within WA, this research provides useful input under the following management categories.

Management Framework

The Department of Environment and Conservation (DEC) have established a Wildlife Management Program to manage the whale shark ecotourism industry. This research and the current information that we have on whale sharks should be made available to the body that oversee this program so that it may be used in any review of current practices and management strategies in the Whale Shark Interaction Management Program. While there is no evidence of specific impacts from the ecotourism industry, valuable information is provided by tour operators through photo identification and sighting records. This information, added to that of the research data on genetics, sightings and movement patterns, will assist in filling in the full picture of whale shark use of NMP over time. Finally, as noted above boat strike is becoming recognised as a potentially significant cause of mortality for whale sharks. This is a threat that can equally be present within NMP given growth in the region and vessel based activities in deeper waters. Consideration should be given to management strategies that may reduce this threat such as awareness raising through education or seasonally reducing speeds in high use areas for whale sharks.

Monitoring

The limited knowledge and fragile status of whale sharks necessitates the monitoring of populations with a variety of techniques, to ensure that information pertinent to their survival is collected in a reliable and accurate manner. Current methods of observation are providing valuable information on the biology and ecology of whale sharks, which is essential for estimating population demographics. These studies then act as the scientific underpinning for informed and effective management strategies.

Of available techniques, mark-recapture analysis based on photo-identification is possibly the simplest and most reliable means of collecting extensive demographic data for population monitoring. This research has led to improvements to the standard photo-identification methods used to identify individual animals. It has also developed genetic markers from small skin samples that can similarly be used to identify individuals. Further it has highlighted the value in identifying individuals repeatedly over time as a means of recording individual migratory patterns and population dynamics. Protocols based on these improvements have been refined for the ongoing monitoring of whale sharks at NMP and should be adopted into the long-term monitoring program there.

Research

There is still much to be learned about whale shark range patterns, life history and connectivity between populations. Several topical and priority issues are detailed below, including future research recommendations.

The issue of population connectivity has yet to be resolved as there is disagreement between photo-identification data which demonstrates no matches between populations in the Indian Ocean and genetic data which shows a homogonous Indian Ocean population. This may be because the genetic information reflects historical patterns of connectivity rather than the current situation. To tease this issue apart, future research could include investigation of whale shark host parasites such as copepods to determine the genetic and location provenance of the parasites, and thus locations visited by the whale shark.

Determining long-term migratory pathways is a central issue in the management of whale sharks at Ningaloo, yet the tagging approaches employed so far have not been able to answer this question due to the relatively short term nature of the tags (ie months). Archival tags would solve part of this problem as they remain attached to the animal and can be retrieved by a diver upon resighting of a tagged animal over a longer period of time. Future research should focus on the deployment of archival tags at Ningaloo, noting that a relatively large number of tags will need to be deployed for this method to be useful as only 20% of the whale sharks that visit Ningaloo are resighted each year.

There is some discrepancy in the interpretation of modelling work derived from photo-identification databases. Our data demonstrates a decrease in abundance of older, larger animals over time (Bradshaw et al 2007). However, a study using a different dataset shows an increase in the number of small sharks (Holmberg et al 2008). Future research would be useful to resolve this difference through combining databases and re-running modeling scenarios.

The photo-identification library created for NMP is a very valuable resource for science and for management. Given the rapid increase in numbers of individuals it now contains, it should now be possible to use this resource to explore any impacts the ecotourism industry may have on the behaviour of whale sharks. Further the combination of information provided through photo-identification, tourism log books and spotter planes can be used to make valuable assessments of trends in abundance and distribution using spatial modeling tools.

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Acknowledgements

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Knowledge Transfer

This is a Baseline study that provides information relevant to management framework, education, research and monitoring of this iconic species in NMP.

6.8 Project 3.2.1: Diversity, abundance and habitat utilisation of sharks and rays

Principle Investigator
John Stevens (CSIRO Marine and Atmospheric Research)

Research Team
Peter Last, William White (CSIRO Marine and Atmospheric Research), Dr Rory McAuley (DoF), Mark Meekan (AIMS)

Project Overview
Most elasmobranchs (sharks and rays) are apex predators and some may even be keystone species in marine ecosystems. Their life history strategies (i.e. long-lived, low reproductive output) make them vulnerable to human pressures such as fishing. Because of their ecosystem role and vulnerability they are often considered good indicators of ecosystem health.

NMP has possibly the largest and most diverse shark and ray fauna found in Australia (up to 118 species). However, the abundance, habitat requirements and distributions of most species is poorly understood. Some species are already economically important to the region for ecotourism (e.g. whale sharks and manta rays) and there are other large species that could become equally valuable such as large stingrays, reef sharks and wedgefish.

Objective
The main objectives of this project were to investigate the elasmobranch faunal composition of NMP, determine the distribution and abundance of species, and examine the habitat utilisation, movement patterns and activity space of selected key species. Of interest to management, was whether existing sanctuary zones were effective for elasmobranch conservation, including protecting aggregation sites reported for some species.

Materials and Methods
Underwater visual census surveys were carried out in the lagoon and at the reef edge (Figure 1) and longline surveys outside the reef (Figure 2) to investigate the faunal composition, distribution and abundance of elasmobranch species throughout NMP. The habitat requirements of about 12 species of elasmobranchs were documented during these surveys. The movement patterns, habitat utilisation and activity space of six key shark and three ray species were examined using acoustic telemetry and satellite tracking. Acoustic tags deployed on elasmobranchs were monitored by listening stations situated in NMP as part of the Australian Acoustic Tagging and Monitoring System (AATAMS).

Key Findings
Forty two species (25 sharks, 17 rays) were documented from NMP (or just outside it). However, we estimate that about 118 species are present in the park at certain times, making it an area of high diversity. By comparison the Great Barrier Reef which contains about the same number of species but is about 70 times the area of NMP.

The diversity and abundance of elasmobranchs was higher in April than December and was generally highest in southern areas of NMP. The most frequently seen

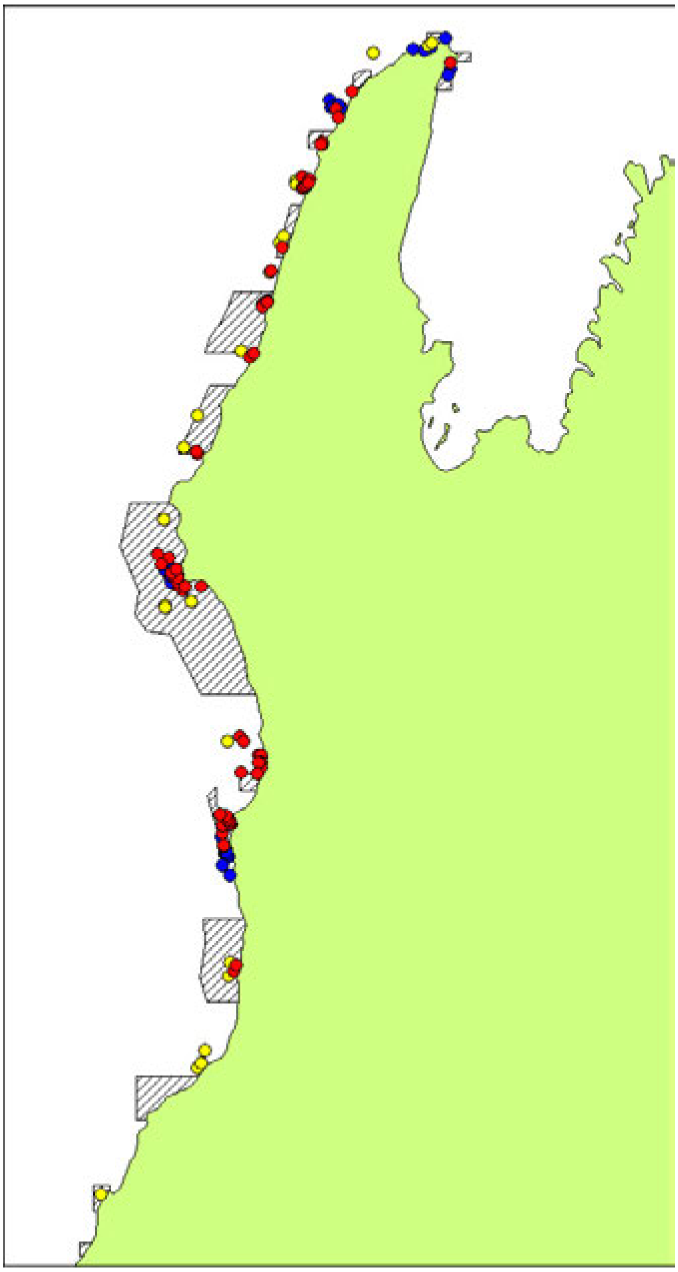

Figure 1 Map showing dive survey sites in NMP used in this study. Hatched areas are sanctuary zones.

elasmobranchs on our visual surveys of the lagoon and reef edge were the Giant Shovelnose Ray *Glaucostegus typus,* the Cowtail Stingray *Pastinachus atrus,* the Bluespotted Maskray *Neotrygon kuhlii,* the Bluespotted Fantail Ray *Taeniura lymma* and the Blacktip Reef Shark *Carcharhinus melanopterus.* The dive surveys provided several new records for NMP and documented species range extensions. Of particular importance was the discovery of a new species of maskray (*Neotrygon ningalooensis*) which may be endemic to NMP (Last *et al.*, 2010; Figure 3). Longline catch rates outside the reef were highest for the Sandbar Shark *Carcharhinus plumbeus,* the Milk Shark *Rhizoprionodon acutus,* the Tiger Shark *Galeocerdo cuvier,* the Blacktip Sharks *C. limbatus/tilstoni* and the Sliteye Shark *Loxodon macrorhinus.* The NMP provides a refuge for the sandbar shark which is commercially exploited elsewhere in Western Australia.

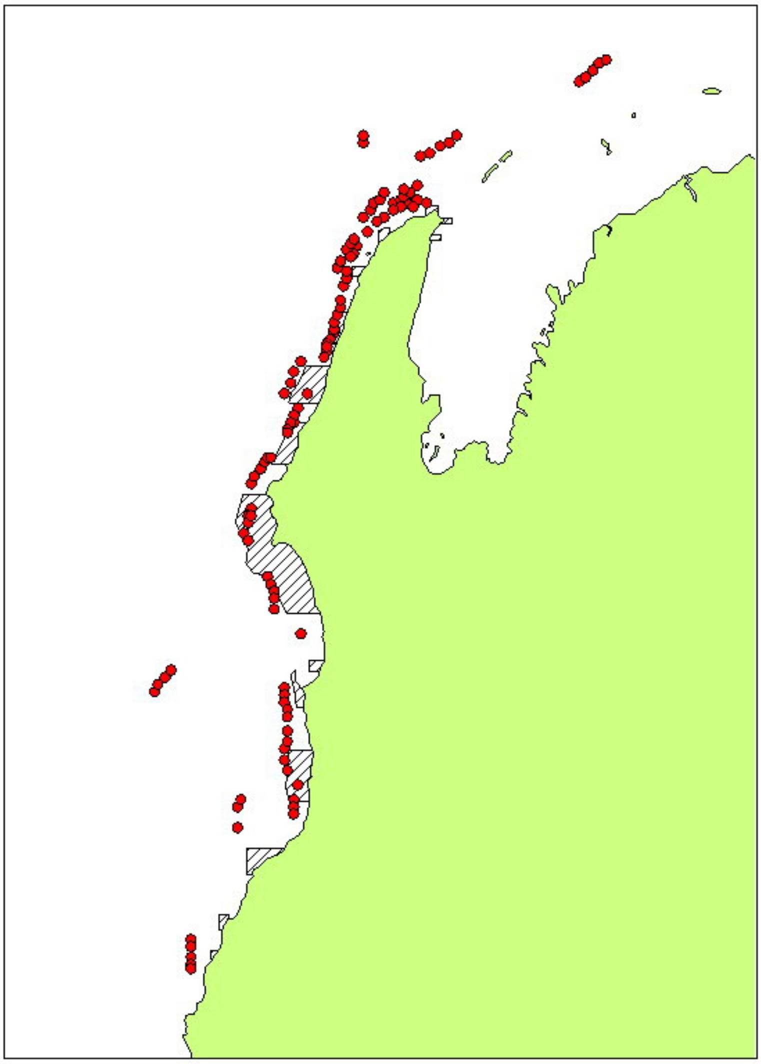

Figure 2 Map showing longline sets by RV 'Naturaliste' in NMP for this study. Hatched areas are sanctuary zones.

Sightings per unit area (SPUA: individuals per 1000 m^2) were higher in sanctuary zones than in non-sanctuary zones for all elasmobranchs combined and for nine out of ten of the most frequently encountered species from lagoon and reef edge dive surveys. Similarly, catch per unit effort (CPUE: individuals per 100 hooks) from longline surveys outside the reef were higher for all elasmobranchs combined and for six out of the eight most frequently caught species inside sanctuary zones.

In terms of habitat requirements, although mangrove areas are limited at NMP, the sand and mangrove habitat (particularly at Mangrove Bay) had the highest sighting rate for elasmobranchs of any of the 11 habitat types. Six species, Blacktip Reef Shark, Lemon Shark *(Negaprion acutidens),* Giant Shovelnose Ray, Pink Whip*ray (Himantura fai),* Cowtail Stingray and Porcupine Ray *(Urogymnus asperrimus)* had their highest sighting rate in the sand and mangrove habitat, highlighting the importance of this habitat type. The new species of maskray was found on mixed habitat of sand and staghorn coral in <3 m depth; however, its dependence on this habitat type is not known at this stage. The lagoon at NMP appears to function as juvenile habitat and nursery areas for several elasmobranch species including Giant Shovelnose Ray, Blacktip Reef Shark and the Grey Reef Shark *C. amblyrhynchos.*

Figure 3. *Neotrygon ningalooensis*, a new species of maskray described after being first discovered during dive surveys in this project.

Data from the acoustic arrays and satellite telemetry shows that the activity space of several shark and ray species is limited, with little exchange between different regions of the Park. Despite the apparent mobility of many of these species they tend to remain within a relatively restricted area lending support to the findings of higher sightings or catch rates from existing sanctuary zones. While bycatch mortality of elasmobranchs from fishing in the NMP is probably low, there may be an indirect effect through capture of their teleost prey species.

Satellite tracking data showed a mixed pattern of transience and residency for Tiger Shark*s (Galeocerdo cuvier)* and Great Hammerhead sharks *(Sphyrna mokarran).* Sharks tagged outside the reef did not remain for long in the NMP area but generally moved north to the North West Shelf and Kimberly region. Some sharks did however re-visit NMP. One Tiger Shark tracked for 13 months moved as far north as Sumba Island, Indonesia and as far south as Esperance suggesting mixing of this species population across WA and with Indonesia (Figure 4). By contrast, an acoustically tagged Tiger Shark remained in the same area around Mangrove Bay for four months, before disappearing and not returning (to date). Limited information on depth behaviour showed *G. cuvier* spent most of their time in relatively shallow water, at times perhaps inside the lagoon, and did not go deeper than 150 m.

Aggregation sites were documented for one shark (black tip reef shark) at Pelican Point in April, and two ray (giant shovelnose ray and cowtail stingray) species at Mangrove Bay, Point Cloates, Pelican and Winderabandi Point, all in sanctuary zones. These aggregations resulted in high densities of elasmobranchs at some sites with a maximum of 840 animals/ha recorded on one transect. The Black Tip Reef Shark and two of the Giant Shovelnose Ray aggregations were of neonatal fish suggesting that these may be nursery areas. However, further work is needed to determine the consistency of these aggregation events.

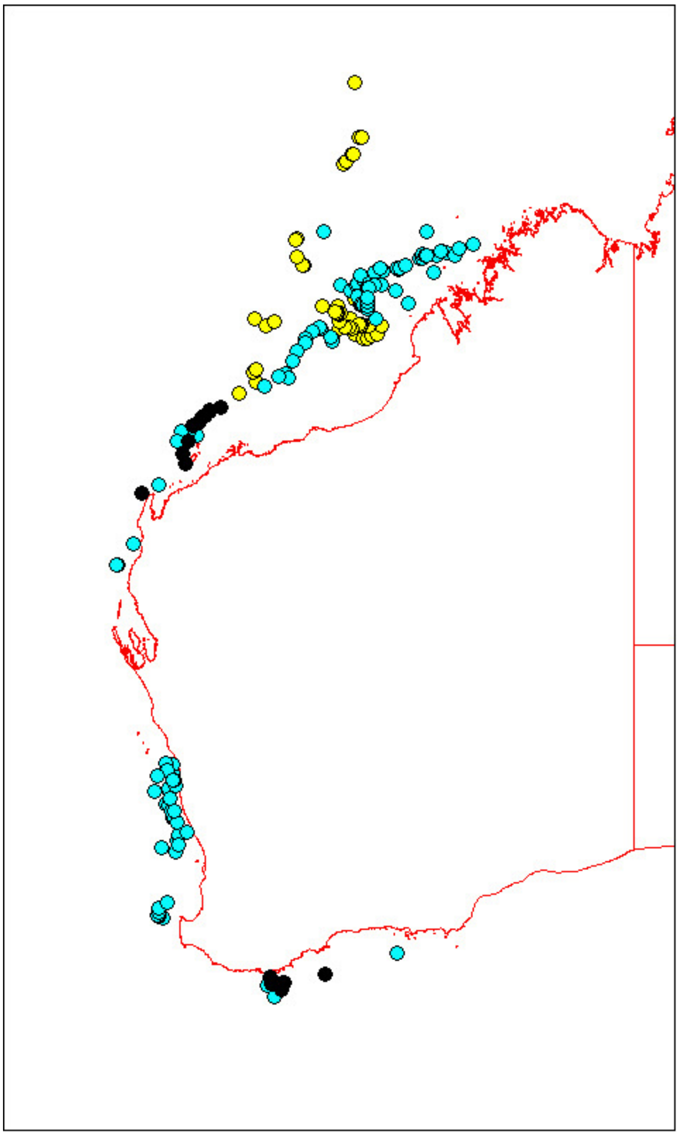

Figure 4. Movement pattern of a Tiger Shark tagged 19/08/08 (SPOT 83859). Yellow is 19/08/08 to 13/10/08, turquoise is 19/10/08 to 05/05/09 and black is 11/05/09 to 03/10/09.

Aggregation sites for juvenile Grey Reef Shark and Black Tip Reef Shark occur at Skeleton Beach, Coral Bay, in summer and possibly also at Pelican, Sandy and Winderabandi Point. The Skeleton Beach aggregations were not observed during our April field trip, possibly because of cool weather conditions at the time. Further work is needed to establish the regularity of these aggregations which can usually be viewed by snorkelling. We observed aggregations of Giant Shovelnose Rays at several sites in April some of which could be viewed from the beach as the fish were only in a few centimetres of water. These aggregations may be tidally related (as well as seasonal) and further investigation is required to establish their regularity. Groups of large stingrays were also observed at some sites, such as Mangrove Bay, where they could provide an attraction for snorkelers although both observer safety and disturbance of the rays would need to be considered.

Management Implications

This project has produced sound baseline information on shark and ray diversity, abundance and distribution in NMP. Many of our findings are preliminary because of poor seasonal coverage as a result of limited resources and the poor weather conditions experienced. We recommend further research and monitoring work is carried out on the elasmobranchs to build on the protocols and findings established through our project. Documenting elasmobranch faunal composition through survey work is problematic and time consuming. Visual survey techniques established for teleost fishes will not work well for elasmobranchs because of generally low sighting rates and the behaviour of many of the highly mobile species which may be either wary or inquisitive. We recommend the use of long transects with multiple divers in lagoon habitats which are often of patchy reef and extensive sand flats, combined with shorter more detailed transects for cryptic species on reefal habitat and Baited Underwater Video (BUV) techniques. Public participation should be sought in viewing existing still and video footage of elasmobranchs taken in NMP.

While we have been able to demonstrate the general effectiveness of existing sanctuary zones for elasmobranchs, we were not able to do this on an individual sanctuary zone basis because of low sightings rates and the high survey effort required. With a number of species utilising the nearshore, shallow environment, habitat partitioning and micro-habitat use would be a fertile area of future research. On-going use should be made of the NRETA/AATAMS acoustic arrays to further research the spatial dynamics of key species and in particular to examine home ranges with respect to existing sanctuary zone size and mixing rates with adjacent and widely separated zones. We chose to satellite track Tiger and Great Hammerhead Sharks because they are two of the largest predatory sharks at NMP and because their prey includes other iconic megafauna in NMP, notably turtles, dugongs and stingrays. However, possibly because we tagged individuals outside the reef where they may be more transitory, they did not remain in the Park for long. In future, it would be better (although more difficult) to tag individuals from the lagoon as these may be more resident individuals.

Finally, we assume that existing bycatch mortality of elasmobranchs by recreational fishers in NMP is low. However, monitoring of catches at boat ramps and angler interviews should be used to confirm or refute this. This information along with education on correct handling and release procedures would also be valuable.

Acknowledgements

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Acoustic tag data are stored on the Integrated Marine Observing System (IMOS) database. Satellite tag data are stored on the CSIRO system (tag release and tag set-up details are on the Tuna–Tag Access database; ptt transmissions from ARGOS are logged and stored automatically). Dive survey data are stored and analysed on a series of 14 Excel files, longline survey data on 7 Excel files and satellite tag data on 7 Excel files. These files are stored on the CSIRO system with copies sent to WAMSI.

Knowledge Transfer

This project is a Baseline study of an ecological asset within NMP. The outcomes from this study will have a number of useful applications for the management of the marine park including informing future research and monitoring of elasmobranchs within the park as well as providing input to reviews of the management framework and education programs relevant to these species. In addition to conservation managers this information will be useful to:

- dive operators
- fisheries scientists and managers
- taxonomists
- general public

6.9 Project 3.2.2: Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation –an overview

Principle Investigator
Russ Babcock (CSIRO Marine and Atmospheric Research)

Research Team
Mat Vanderklift, Mick Haywood, Richard Pillans (CSIRO Marine and Atmospheric Research), Glenn Hyndes, Adriana Verges and Jason How, (ECU), Euan Harvey, Ben Fitzpatrick; Bob Black, Jane Prince, Anne Brearley (UWA)

Project Overview
NMP, established in 1987, is a Multiple-Use Marine Park with several different types of management zoning. The zonings are intended to achieve a wide range of goals, but particularly to preserve biodiversity and ecological values within the park. In practical terms the main impact of zoning on human usage has been to restrict levels of commercial and recreational fishing within the park. A review of the NMP Management Plan beginning in 2000 led to the release of a revised Management Plan in 2005 which extended the park southward and increased the area within the park contained within sanctuary zones. However, there was some controversy at the time over the scientific basis on which to plan the size and placement of sanctuary zones along with their overall effectiveness as a biodiversity conservation tool.

This project was designed to assess the effectiveness of the zoning scheme at NMP by measuring the distribution and abundance of organisms on the reef and assessing their variation in the context of both previous and current zoning (size, age, configuration) and habitat. This was accomplished through a series of subprojects that focussed on various species groups in the lagoon system (fish (3.2.2a, 3.2.2e, 3.2.2f), rock lobster (3.2.2d), intertidal invertebrates (3.2.2b)) and ecological processes (herbivory and trophic cascade effects (3.2.2c)). This overview reports describes the collective findings and discusses the effectiveness of the zoning scheme. For specific information on a species group or topic, see the relevant subproject (below)

Objectives
The overall aim of this project was to assess the effectiveness of sanctuary zones in the lagoon system of NMP in protecting biodiversity and coral reef health. Sub projects were designed to address the following management questions which sought a better understanding of the current status of biodiversity and patterns of distribution throughout the park and evidence of the appropriateness of current management strategies:

- What is the species diversity, abundance and distribution of key flora and fauna in selected representative habitats;
- How do exploited (historic and current) and unexploited areas of NMP compare in regards to the above question;
- How do the movement patterns, life history and habitat use of key fished species interact with design of sanctuary zones to determine zone effectiveness;
- Do variations in the abundance of key predatory species measurably affect prey populations;
- Do variations in predator abundance indirectly affect reef ecosystem structure including the abundance of grazers, algae and corals and corallivorous gastropods (*Drupella*);

- Are current management arrangements/regulations appropriate for preserving the biodiversity represented within the park;
- What should management targets be for key species and ecological processes within the park; and
- What species/processes should be monitored in order to most cost effectively ensure targets are met.

Key Findings

The assessment of the zoning of NMP has in general confirmed that the zoning implemented in 1991 has achieved positive outcomes in terms of biodiversity protection and that the recent re-zoning is likely to achieve further conservation outcomes as intended. It also highlights the need for ongoing evaluation of marine park effectiveness in relation to both zoning and overall management as there are indications from a range of sources that there may be aspects of park configuration requiring further management action in order to realise park management goals.

Surveys confirmed that the expansion of sanctuary zones to include additional habitats and regions in the north and south of the park has led to the inclusion of a broader suite of fish assemblages, lobster populations and intertidal invertebrates. It has also broadened the diversity of ecological processes such as herbivore trophic groups, which also vary from the north to the south of the park. Similarly, the expanded inclusion of reef slope habitats has resulted in a much more representative system of no-take areas since reef slope fish and, invertebrate assemblages and ecological processes are all distinct from those on reef flat and reef slopes. At still finer scales distinctive assemblages of fish were also found among sub-habitat types within the lagoons. Overall the findings have generally confirmed that the rezoning of the park has achieved a more comprehensive representation of ecological processes and biodiversity. Further, surveys have provided information that can be used to inform future revisions of park zoning intended to more fully represent NMPs marine biodiversity.

Assessments of fish populations across a range of previously established sanctuary zones revealed higher biomass of targeted species spangled emperor (*Lethrinus nebulosus*), yellowtailed emperor (*Lethrinus atkinsoni*) and cod (*Epinephelus rivulatus)* across multiple sanctuary zones. Other species showed significant increases in specific sanctuary zones, a pattern that depended on regional variation in the distribution of some species (e.g. mangrove jack *Lutjanus argentimaculatus* at Bundegi). The size of these effects was relatively small, generally less than a doubling in biomass. Importantly, surveys also revealed that for some taxa the differences between sanctuary zones and fished areas were smaller than variations in targeted species biomass related to gradients in fishing pressure, with sharks, trevallies, groupers and emperors showing significantly higher biomass in areas with low fishing pressure.

Taken across both these comparisons, these surveys provide evidence that sanctuary zones are protecting targeted species, and that recreational fishing has had a measurable effect on populations of targeted species at Ningaloo. This conclusion is further supported by comparisons of density of spangled emperor in our study with densities estimated by similar surveys in 1987. Densities of spangled emperor at Osprey Sanctuary zone in 2006 are approximately half of the densities recorded in 1987, while in adjacent recreationally fished areas densities were around 10% of the 1987 levels. Similarly, populations of rock lobsters appear to be much lower than historical levels in the park, despite the cessation of commercial lobster fishing in the 1980s, with western rock lobster relatively abundant only in a small section of one of the no-take areas of the park.

There were few indications that indirect effects of fishing are having a substantial impact on food webs at Ningaloo. While some small predatory fish species (e.g. wrasses) were less abundant inside no-take zones, possibly due to competition or predation by protected target species, these effects did not extend to other trophic groups and most herbivorous fish, invertebrates (urchins and *Drupella*), corals and macroalgae showed no consistent trends between no-take sanctuary zones and recreationally fished areas.

Parrotfish were found by several independent surveys to be more abundant in no-take zones. The mechanisms responsible for this pattern are not clear, but it is important to understand them if this finding is to be fully used to inform management practices aimed at promoting the resilience of coral reef ecosystems. Fish herbivory (as opposed to invertebrate herbivory) was found to be a very important process on Ningaloo Reef, which probably enables corals to thrive. Parrotfish were found to be important grazers on the reef, but there were numerous other groups such as Kyphosids (drummers) and Acanthurids (surgeonfish) which were found to be more important in some circumstances, particularly in terms of grazing on large macroalgae. Ecosystems at Ningaloo benefit from a large suite of grazing species which are more diverse than grazer assemblages on equivalent coastal reefs at similar latitudes on Australia's east coast, and by comparing the biomass of grazing fish and macroalgae we have shown that biomasses of 100 $kg.ha^{-1}$ may be required to maintain low macroalgal biomass on these reefs.

Tracking of fish using acoustic tagging at NMP have revealed the importance of particular habitats for key species as well as the timing of important behaviours such as spawning. Tracking has shown that the habitat utilization areas of most of the species tracked has been smaller than was assumed prior to this study. Based on measurements of individual movement patterns obtained through acoustic tracking it appears that most of the sanctuary zones within NMP are of a size adequate to protect a significant proportion of the fish populations. For example the mean diameter of core habitat areas for a range of groupers of less than 1 km, and for spangled emperor 2.5-3-5 km. While the majority of sanctuary zones are larger than this, the linear extent of sanctuary zones in the northern part of the park is approximately 2.8km, about the same as the size of the area encompassed by the movements of an individual spangled emperor. Movements of other species such as gold spot trevally (*Carangoides fulvoguttatus*) are larger than this however and smaller sanctuary zones may not be adequate to protect such species. The sizes of sanctuary zones for some habitats, such as reef slopes, may be too small relative to the areas encompassed by the movements of the species that inhabit them. Planning for future sanctuary zones could incorporate these measurements into modelling approaches to provide a basis for determining optimal size of sanctuary zones.

Management Implications

Key recommendations from the project relate to both direct management actions and recommendations for further research. It is important that future reviews of zoning take these findings into account in order to ensure the comprehensiveness, adequacy and representativeness of overall park zoning. Additional actions across the park and not restricted to zoning may also be required in order to adequately address some issues such as overall declines in fish and lobster abundance. Further research and monitoring is recommended in order to assess the effectiveness of newly created sanctuary zones before zoning reviews are undertaken, or any more general steps to conserve populations at risk are taken. This project has also revealed likely trophic interactions that have the potential to impact on the overall biodiversity of the park and to be used in the context of ensuring the resilience of the NMP ecosystem. These interactions are not yet understood and should be further investigated in order to assess whether further management actions are required at NMP, and whether any insights gained can be used in the context of marine parks in other parts of Western Australia.

Findings from this research has direct application to the management framework for NMP and can best be summarised by the points below that should be considered in the next review of the NMP Management Plan

- Lagoon and reef flat areas are well represented within the sanctuary zone system of NMP however many shoreline areas within sanctuary zones are exposed to fishing because of special purpose shore based angling zones. These zones may put populations of some fish (e.g. spangled emperor *Lethrinus nebulosus*) that use shoreline areas for feeding and/or migration within such sanctuary zones at disproportionate risk of capture.
- The differentiation of fish assemblages in the north of the NMP and MIMMA from those further south, and the verification that fish assemblages in reef slope habitats, and in deeper waters, are distinct from those in shallower reef flat and lagoon habitats, suggests that it is important to include these habitats in the network of sanctuary zones at NMP. Currently sanctuary zones in the northern section of the park include the lowest representation of these habitats of any region in the park, yet they are the most heavily fished and likely to be in greatest need of protection now and in the future.
- Sanctuary zones in the northern region of the park are among the smallest of any region, meaning that even for relatively sedentary species such as spangled emperor their effectiveness may be reduced. The linear extent of these zones may need to be increased in order to achieve restoration targets in this region since the mean size of the home range of an average spangled emperor for example is approximately the same size or larger than the sizes of the sanctuary zones, meaning that fish will likely spend a large proportion of their time outside zone boundaries, and therefore in areas where they are susceptible to fishing.
- Given the demonstrated impact of access to the park and fishing pressure on fish populations, no further development of access points should be undertaken without due consideration for the context of the stated goals of the marine park i.e. conservation and restoration of natural values of NMP.
- Uncertainty about the rate of recovery of lobster populations in the park and the spatially restricted nature of high density populations of western rock lobster in parts of Bateman Bay, may mean that additional sites, including similar suitable habitat may need to be identified for protection of this species at NMP.

Research findings also have application to the ongoing monitoring and research program within NMP to improve our understanding and management of marine resources over the long-term. The following subprojects provide baseline information along with suitable protocols and reference sites from which to implement a long-term monitoring program of a variety of taxa and ecological processes active at NMP.

- In many cases the rate of response of fish populations to protection from fishing has been shown to be rapid. The rate of response has the potential to provide significant information on the condition of the ecosystem, including resilience and response to disturbance. This means that there is a clear need to continue monitoring of at least a subset of sites if we are to be able to understand the nature of responses. The desirability of such data is well illustrated by reference to our measurements of change at the Osprey Sanctuary Zone. We know densities were different in 2006 than they were in 1987, but we have no idea what the densities were over the intervening 20 years, whether 2007 was just a “low” year, or 1987 a “high” one. Regular and ongoing assessment is therefore essential for providing the system understanding required to underpin adaptive management. Such studies need to be repeated, not replaced by alternative monitoring, at least until an effective cross calibration of methods has been achieved.
- There is no indication of cascading trophic effects on benthic organisms, however there was an indication that there are effects on populations of some small fish

prey/competitor species. In addition, the observation of higher abundances of key grazers inside sanctuary zones suggests that some complex indirect effects might be occurring, although the nature of these effects remain unclear. This suggests that while the effects of fishing at higher trophic levels have not yet had serious effects on overall ecosystem structure, there exists potential for indirect trophic effects to become important should predator densities change dramatically, or as a result of extreme natural events. Regular monitoring should continue to assess the density and population structure of key fish species, key invertebrates, algae and corals.

- The spatially restricted location of dense populations of western rock lobster populations, and strong influence of habitat on lobster abundance and population structure make western rock lobster populations at Ningaloo particularly vulnerable. These populations could be heavily reduced by the actions of a few individuals in a matter of days, probably without knowing that this is effectively the last population left at NMP. Ongoing monitoring, specifically targeting suitable habitats within a select group of existing and newly declared sanctuaries, is required in order to determine the health of lobster populations and the degree to which they may respond positively to protection by sanctuary zones.

In addition, a number of research opportunities have been identified that can extend the information learned so far into new areas applicable for the ongoing management of NMP:

- If seasonal spatial closures are to be used as a complement to sanctuary zoning, it is important to improve our knowledge of the timing and location of spawning behaviours of key target fish species such as *Lethrinus nebulosus* and groupers in NMP.
- Mechanisms should be sought to ensure the ongoing presence of the IMOS AATAMS tracking array and cross-shelf lines at NMP as a source of strategic science that can inform decisions in other parts of northwest WA.
- Mathematical models are tools increasingly being used to maximise the ability to understand the implications of how of fish habits and habitat use interacts with human uses of the park in order to assist management. The data obtained in this study provides the opportunity to include fish behaviour in these models, just as the models currently include human behaviour and thus to use this information to inform future management decisions relating to the zoning of the NMP.
- Higher grazer biomass in sanctuary zones may be evidence of a novel resilience mechanism. In order to capitalise on this as a potential management tool we need to better understand the mechanism underpinning it, or risk unintended outcomes. Understanding of the mechanisms underlying the lower biomass of parrotfish in fished areas should also be the focus of future research effort.

Data Resources

See individual sub projects

Knowledge Transfer

See individual sub projects for more detail, however overall this research has direct application to management framework strategies, research and monitoring and should be taken into consideration by personnel in Marine policy and Planning Branch, Marine Science Program as well as the regional District Office.

6.10 Project 3.2.2a: Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation: broad-scale fish census

Principle Investigator
Russ Babcock (CSIRO Marine and Atmospheric Research)

Research Team
Mick Haywood, Mat Vanderklift, Geordie Clapin, Matt Kleczkowski, Darren Dennis, Tim Skewes, Dave Milton, Nicole Murphy, Richard Pillans, Andrew Limbourn (CSIRO Marine and Atmospheric Research)

Project Overview
Fishing is perhaps the most ubiquitous of human influences in the ocean. The impact of fishing on target species is often intense, and frequently targets predatory species (Crowder et al. 2008). In developed nations, a large proportion of the catch is taken by recreational fishers (Arlinghaus & Cooke 2005). Due to the difficulty of managing multiple sectors, often with multiple target species along with the need to manage the ecosystems that support the target species as well as the species themselves, ecosystem-based management is increasingly being used (Crowder et al 2008). In Western Australia, Marine Protected Areas (MPAs) are used as a form of spatial management with multiple goals, among which protection from fishing falls within a much broader mandate of conserving biodiversity and ecological processes.

Areas that are closed to fishing may directly protect the fish populations that reside within them, they are also thought to benefit adjacent fisheries by emigration of adult and juvenile fishes (the “spillover” effect; Rowley 1994) and the export of pelagic eggs and larvae (Roberts and Polunin 1991, Roberts 1995). Whether these benefits occur or not is dependent on a range of factors such as the size of the reserve and the mobility of the adult and larval fish. Many species of coral reef fish are strongly site-attached with relatively small home-ranges (Munro and Williams 1985, Zeller 1999) and some studies have suggested coral reef fish larvae may be retained in the vicinity of their natal reefs (Leis and Goldman 1987, Kobayashi 1989, Almanay et al. 2007). These characteristics may mean that for many species the benefits of protection from exploitation are localised to the area within and immediately adjacent to the reserve.

A key ecological value identified in the NMP Management Plan is the diversity of fish found within the Park, and fishing (particularly recreational) was identified as a major pressure on this value. The NMP zoning strategy is the key mechanism used to ensure the species distribution and abundance of finfish species are not unacceptably impacted by recreational and commercial fishing.

Objectives
The specific objectives of this project were to survey fish taxa targeted by anglers (mainly species within the families Labridae, Lethrinidae, Lutjanidae, Serranidae, and Carangidae), as well as taxa that may be affected by incidental capture in the lagoon system of NMP (Haemulidae and sharks) in order to:

1. Measure the distribution, abundance and size-structure of their populations within the NMP,
2. Provide data for quantitative comparison of these parameters among NMP management zones (pre-2005 sanctuary zones, new sanctuary zones, benthic protection zones, recreational zones and general use zones), and

3. Provide data that will form the basis for being able to:
   - Measure the rate and magnitude of any changes in target species population abundance or size structure related to changes in marine park zoning,
   - Determine how patterns in abundance and size structure of target species vary with respect to factors such as size of reserve, type of reserve, distance from boundary and fish life-history, and
   - Parameterize and test spatially-explicit models of target species populations.

Materials and Methods

Survey sites in NMP were selected from among coastal areas stretching from of Gnaraloo in the south to the Muiron Islands in the north (Figure 1). Sites were chosen to take into account location of management zone, age of management zone, and habitat. Within each management zone, samples were stratified by habitat (outer reef slope, reef flat, and lagoon), and distance from zone boundary.

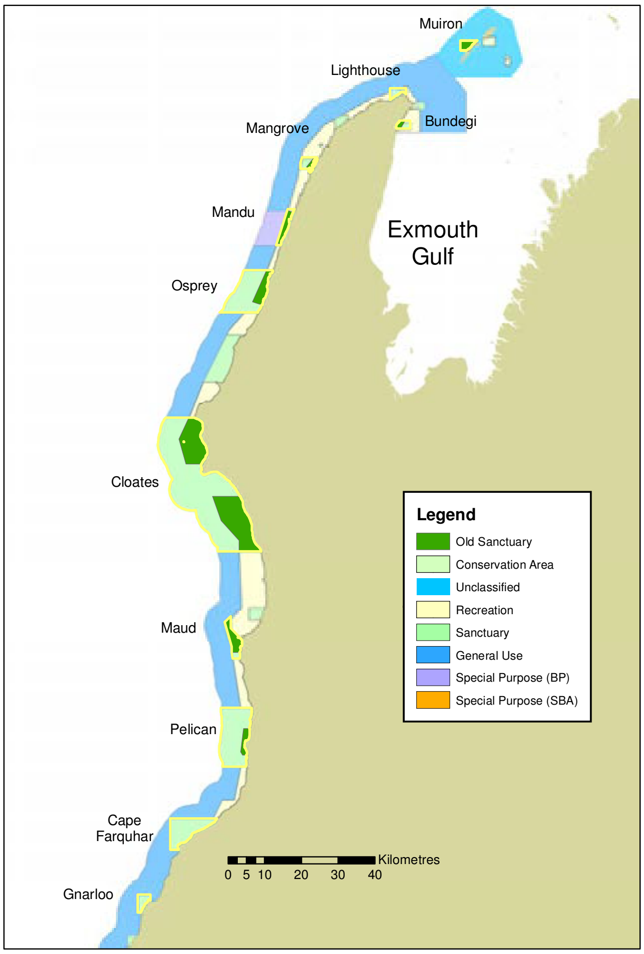


Figure 1. Survey sites sampled in NMP – sanctuary zones outlined in yellow were sampled in these surveys.

Fishes within NMP were sampled using underwater visual census (UVC). At each site a single SCUBA diver swimming along a 100m x 10m belt transect, identifying, counting, and estimating the total length of fishes observed within the transect. Divers also characterized the benthic habitat by estimating percent cover of sessile life forms (e.g.

coral, algae) and substratum classes (e.g. sand, rubble, boulders), and the cover of live versus dead coral (English et al. 1997), as well as depth, visibility, and the compass bearing of the direction swum.
Censuses focused on several discrete guilds of fish rather than the entire fish assemblage. The guilds under investigation included major predatory fishes that are targeted by recreational fishers or taxa that may be incidentally captured (Lethrinidae, Lutjanidae, Serranidae, Carangidae, Scombridae, Labridae, Haemulidae, and Carcharhinidae), as well as the main herbivorous families (Scaridae, Siganidae, Acanthuridae, and Kyphosidae).

We were able to take advantage of an earlier survey conducted in 1987 (Ayling and Ayling 1987) on the iconic angling target species spangled edmperor (*Lethrinus nebulosus)* in the Osprey Sanctuary. Based on maps provided in the Ayling study we re-sampled 76 of the same sites, using almost identical techniques (the primary distinction being the length and width of the transects: Ayling's transects were 50 × 10m).

Key Findings

Fish assemblage structure showed clear trends with habitat and from north to south. There was also a significant overall difference in fish assemblages inside and outside sanctuary zones (Figure 2). Differences in fish assemblages were also significant among reef slope, reef flat and lagoon habitats.

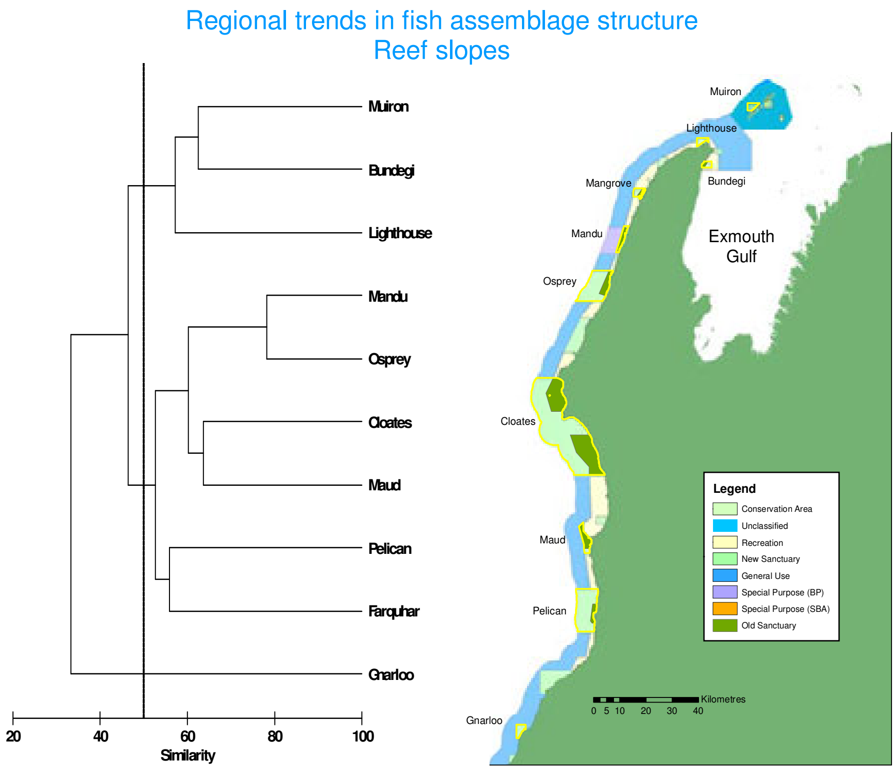


Figure 2. Latitudinal gradient in reef slope fish assemblage structure along NMP. Data were from reef slope sites only, averaged by Region, fourth root transformed and using Bray-Curtis similarity.

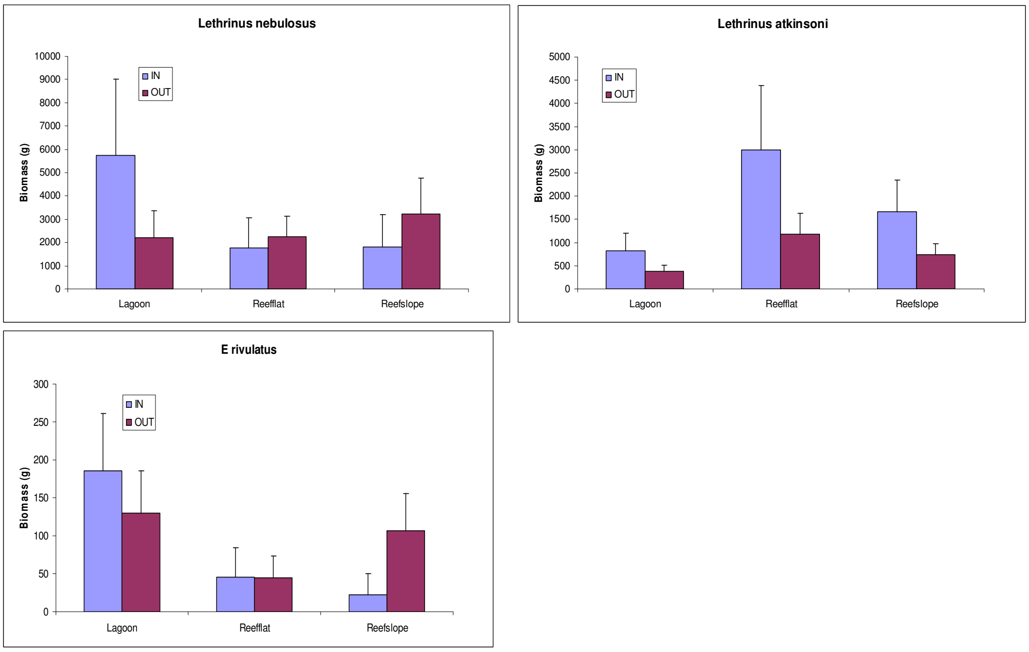
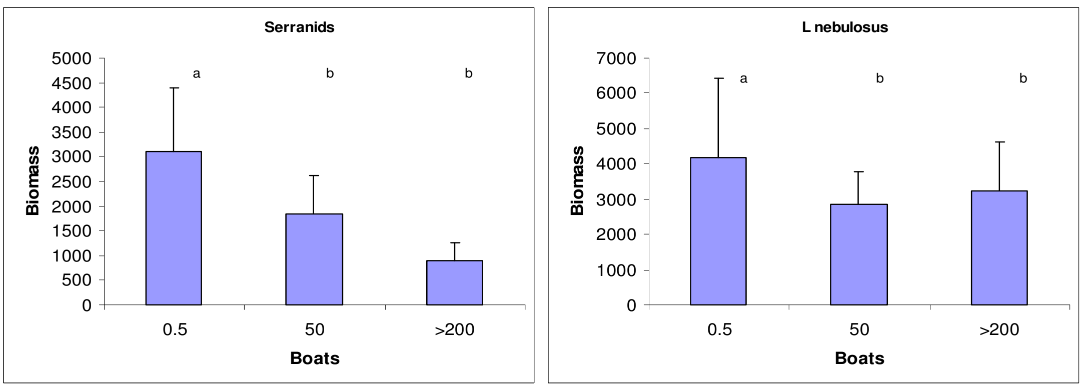


Figure 3. Habitat and zoning-related trends in biomass of selected top target taxa in pre-existing Sanctuary Zone Regions in NMP. Data are means per transect (g + 95% CI).

Among the species most commonly targeted by anglers there was an overall increase in biomass for the yellow tailed emperor (*L. atkinsoni*) which was between 0.9 and 2.4 times greater in pre-existing sanctuary zones, as well as in the spangled emperor (*L. nebulosus*) with biomass between 0.4 and 2.8 times greater. These trends in fish biomass were largely driven by the size structure of populations in sanctuary zones. The trends in both of these species were strongest in fish greater than the minimum legal size, consistent with fishing being the factor driving these differences. Cod *(Epinephelus rivulatus)* was also present at higher biomass within sanctuary zones.

Densities of spangled emperor at Osprey Sanctuary zone in 2006 were approximately half of the densities recorded in 1987, while in adjacent recreationally fished areas densities they were around 10% of the 1987 levels.

Significant variation in fish biomass was measured in relation to fishing pressure for many fish that are key targets for recreational fishing. These species included large groupers, spangled emperors, trevallies and sharks, with biomass tending to be significantly lower in areas with higher levels of recreational fishing pressure (Figure 4).



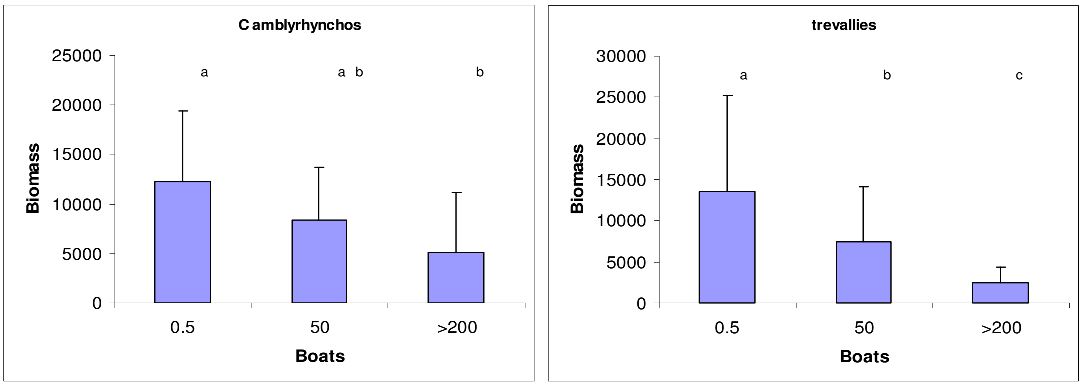


Figure 4 Biomass of selected top target taxa in NMP relative to fishing pressure. Biomass data are means per transect (g + 95% CI), Fishing effort is boats per year from all 6nm statistical reporting blocks (Sumner et al 2002) in which data were collected. Letters indicate levels of fishing pressure shown to differ in the basis of pairwise comparisons.

Management Implications

Surveys confirmed that the expansion of no-take sanctuary zones to include additional habitats and regions in the north and south of the park has led to the inclusion of a broader suite of fish assemblages. Similarly, the expanded inclusion of reef slope habitats has resulted in a much more representative system of no-take areas since reef slope fish assemblages and ecological processes are all distinct from those on reef flat and reef slopes. Overall the findings have generally confirmed that the rezoning of the park has achieved a more comprehensive representation of ecological processes and biodiversity. Surveys have also provided information that can be used to inform future revisions of park zoning intended to more fully represent the parks marine biodiversity.

Assessments of fish populations across a range of previously established sanctuary zones revealed higher biomass of targeted species spangled emperor, yellowtailed emperor and cod across multiple sanctuary zones. Importantly, surveys also revealed that, for a large proportion of target taxa, variations in biomass are significantly related to gradients of fishing pressure and that the differences between sanctuary zones and fished areas were smaller than variations in targeted species biomass related to gradients in fishing pressure. Considering that there appear to have been declines in the biomass of this species even within the Osprey sanctuary zone since 1987, and that declines outside it were even greater, our observations suggest that the previous park zoning was not sufficient to prevent the decline of spangled emperor populations in the area. Given the continuing increase in fishing pressure, there is an urgent need to assess whether the current zoning provisions in the park are achieving their goal of preventing further declines, or whether additional steps need to be taken to protect targeted fish populations.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Data collection was carried out by diver surveys (underwater visual census) both inside and outside sanctuary zones at broad scales along the length of the reef (more than 400 sites sampled in 2006 and 2007). Data is currently in the form of an ACCESS databases and is held on the CSIRO server.

Knowledge Transfer

This is an Inventory and Baseline study that provides not only baseline dataset but also methodology and reference sites for long-term monitoring of fish assemblages in NMP. This information should be used by marine park planners and managers in supporting the current management framework and making amendments in future reviews. It should also be used by research and monitoring staff in their programs.

6.11 Project 3.2.2b: Diversity, abundance and distribution of intertidal invertebrate species in NMP

Principle Investigator
Dr. Robert Black (School of Animal Biology, UWA)

Research Team
Prof. Michael S. Johnson, Dr. Jane Prince, Dr. Anne Brearley (UWA)

Project Overview
Shoreline intertidal reefs are a prominent and important feature of NMP and are important biologically as they contain significant biodiversity and habitat and socially as they are easily accessible and attract a variety of recreational uses. High use of these areas can make them vulnerable, in particular to activities such as shell collecting which was anecdotally very high in the 1960s and 1970s. To date, though there is little information on species and assemblage diversity, abundance and distribution.

A quantitative pilot study of the composition of the benthic community of macro-invertebrates on intertidal rocky platforms was undertaken to (i) provide detailed information on variation in biodiversity along the length of NMP and (ii) determine the appropriate design of a monitoring protocol powerful enough to detect measurable change. These general overall aims were in the context of the NMP Draft Management Plan of 2005, which set out a vision of maintaining the ecological values in the Park, and protecting it from adverse human impacts.

Objective
There were three important management questions that were relevant to our work on the intertidal rocky platforms:

- What is the species diversity of key flora and fauna in selected representative habitats?
- What is the abundance, size composition and distribution of these key species?
- How do the current abundances of targeted and non-targeted species (subtidal and intertidal) compare with the natural abundances of these species in NMP?

Materials and Methods
The design of research and monitoring schemes must include several crucial features: (1) adequate, replicated sampling for each combination of time, location and any other controlled variable; (2) adequate, replicated sampling in areas with and without human impacts; and (3) pre-defined, quantitative criteria for what constitutes an important trend (temporal or spatial). Even well-designed studies have to overcome the challenges of i) natural variability and patchiness at different temporal and spatial scales, and ii) natural events that overwhelm, obscure, or counteract the effects of human impacts.

This project examined the assemblages of macroinvertebrates at 36 sites on rocky intertidal platforms from Mildura Wreck in the north to 3 Mile in the south of NMP between 2007 and 2010, visiting 18 sites twice. We used careful searches of replicate 1-m^2 quadrats to quantify macroinvertebrates at these sites. Twenty two of these sites were within sanctuary zones, with seven sanctuary zones having at least two sites. Eleven sites were close to but outside Jurabi, Bateman Bay, Pelican, Gnarraloo Bay, and 3 Mile Sanctuary Zones, while the remaining three, outside sanctuary zones, improved the geographic distribution of the sites. This array of sites, and sampling times were selected so that comparisons could be made among geographical regions in NMP, between management areas, and over time.

Key Findings

Our study has produced a list of macroinvertebrates at 36 sites within NMP, with quantitative estimates of their distribution and abundance. We measured the size composition of just one species, the small giant clam, *Tridacna maxima*. As far as we know, our study is the first one to estimate abundances at so many sites within the Park, so these are the first estimates of “natural abundances”. The specific features of our study can be summarized in the following points.

This study provides a start to an inventory of invertebrates on intertidal platforms at NMP. Two hundred eighty nine species were identified (127 species were gastropods). Of these, 92 species were represented by single individuals. Only 3 species may be restricted to Ningaloo Reef, the other identified species with know distributions also occur outside the Park, many extending to other states. This represents a high biodiversity as expected for intertidal rocky platforms.

In samples from 2007 and 2009, analyses of 15 of the most abundant species, representing most kinds of feeding by marine invertebrates, indicated that spatial variation was pervasive and overwhelmed temporal variation, as might be expected over the short time interval, and from species being long-lived. Spatial variation at the scales of our study (among geographical regions, among sites within regions, among quadrats within sites) could be very large, but was not universal, and depended on the species considered.

Spatial and temporal variability in the composition of the assemblages of invertebrates was similar to that of the individual species; spatial variability predominated over temporal variation, and demonstrated that the assemblages had different membership according to the region of the Park. Sites in Sanctuary Zones, in Special Purpose Areas, onshore from offshore Sanctuary Zones, and in Recreation Zones showed broad overlap in ordinations of the assemblages, indicating that the sites in Sanctuary Zones represent much of the variation in composition of the macroinvertebrates on rocky platforms.

Part of the spatial variation in assemblages and individual species appeared to be related to particular features of the physical environment within m^2 areas, the whole site, the whole platform, and the larger setting of the platforms. Correcting for these features statistically may allow refined measures of differences and changes. These physical features and others helped organize the variety of platforms into five morphotypes that may help in selection of sites for future studies, and explain features of the distribution of particular species.

Cowries (*Cypraea cauputserpentis* and *C. moneta*) provided a case study for detecting differences outside and inside Jurabi Sanctuary Zone. Their overall scarceness and variable abundance meant that detecting a twofold difference between inside and outside the zone, even with 4 replicate sites in each condition, would have very low statistical power, or require impossibly large number of replicate sites.

Understanding variability of recruitment and mortality is essential for assessing changes due to perceived disturbances or attempts to conserve populations. An intensive study of small giant clams, *Tridacna maxima*, at 20 sites substituted space for time in the absence of long-term studies. Our interpretations indicated variability in recruitment and mortality, including failures of cohorts to recruit and catastrophic events of mortality. Consistency of recruitment was greater toward the north of the Park, on intertidal platforms with greater complexity across their widths, and with smoother surfaces in the part of the platform occupied by the clams (Figure 1). Our calculations suggested that the clams had a median age of 13 years.

In a test of some predictions from power analyses, we used four sites inside Jurabi Sanctuary Zone and four sites outside to determine whether we could detect an effect of Sanctuary Zone. The assemblages of invertebrates differed inside and outside of the zone, and simulations suggested that although the eight sites were necessary to retain that differentiation, the number of quadrats per site could be reduced.

Management Implications

Managers must understand the extent and nature of natural variation in abundances of intertidal organisms at different places at the same time and the same place at different times. Our data show individual species varying from none to lots, from place to place within the Park, and between 2007 and 2010 from some to not any. Against this background of spatial and temporal variation, desired trends for "diversity" and "biomass" to be "constant or positive" are clearly ambitious. Managers must distinguish between changes that are major rather than minor, foreseen rather than accidental, and prolonged rather than transient.

The spatial variability in biodiversity though points to the importance of sanctuary zones throughout NMP across this habitat to ensure protection for representative species assemblages from each region.

The main conclusion from our study of intertidal platforms in NMP is that spatial and temporal variation in the composition of the assemblage of the macroinvertebrates is so large that little could be predicted. The prognosis from our power analyses is that detecting differences between sites under different management regimes will be difficult, as will be detecting changes over time. The essential, and as yet missing, decision by managers is what effect size is important enough to elicit remedial action.

The above notwithstanding, long-term monitoring of these communities should take into account the following points:

- The appropriate unit of independent replication should be a "site" (as used in this project), and the prognosis from our power analyses is that, even for several fold effect sizes, the number of replicate sites per treatment should be several;
- Because of the regional differences in species composition of assemblages of intertidal invertebrates, continued monitoring schemes must include sites along the length of NMP;
- Additional sampling of intertidal invertebrates will reveal species not detected by this study. This is a natural, expected consequence of the underlying nature of assemblages of invertebrates. Many species are rare; most species occur at low densities; and
- Long-term studies spanning 5 to 10 years or more will be required to reveal the dynamics of local populations of long-lived intertidal invertebrates such as *Tricacna maxima* and *Echinometra mathaei*. Some species will be ephemeral.

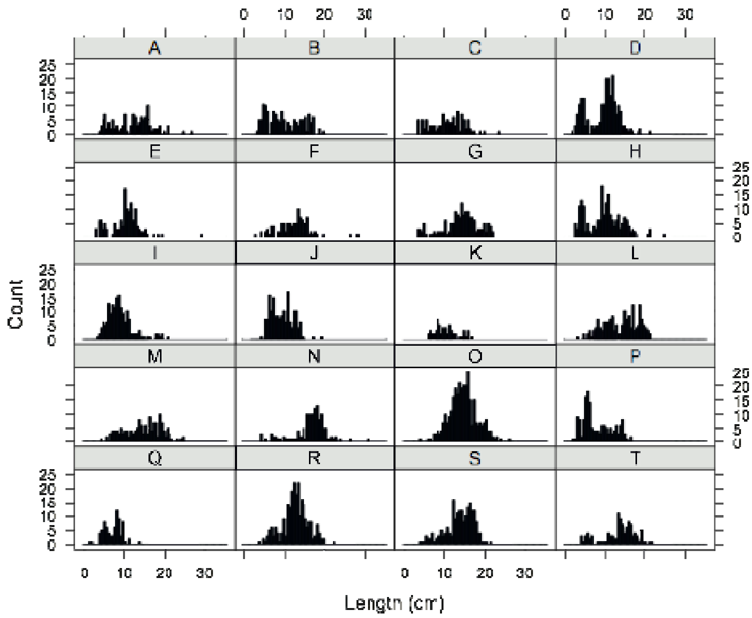

Figure 1. Size frequency distributions with intervals of 0.5 cm for the lengths of *Tridacna maxima* at twenty sites in Ningaloo Marine Park. The labels above the distribution for each panel are codes for the sites. The sites are in order from north (A, Mildura Wreck) to south (T, 3 Mile) from upper left to lower right.

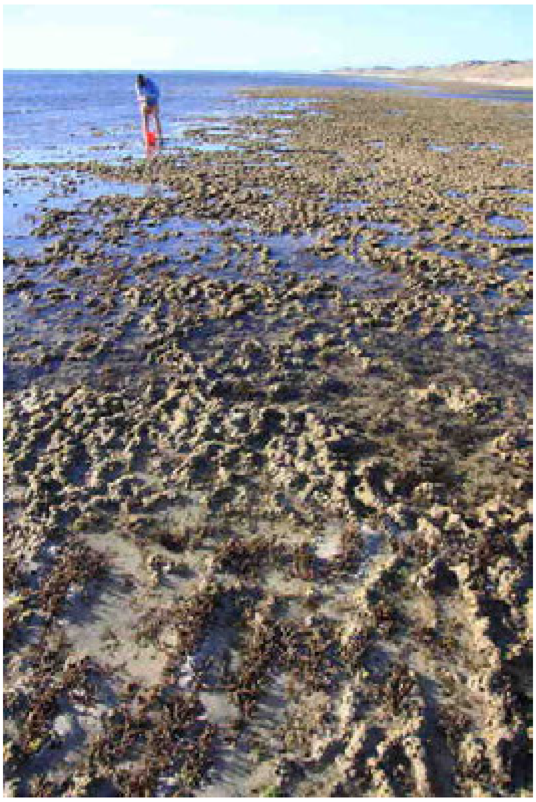

Photo by Todd Bond 2009

Picture 1. This image shows the texture of a site at Bateman Bay with evidence of sand accumulating on the surface in the foreground.

Figure 2. Images of fifteen of the most abundant species found on rocky intertidal platforms in Ningaloo Marine Park.

Acknowledgements
Dr. Alan Kendrick and staff from the Exmouth Department of Environment and Conservation assisted with sampling in 2007, suggested sites that we should examine. We appreciate Alan's special interest in the molluscs at our sites, and his continued support for our work. For assistance with identifications we acknowledge Shirley Slack-Smith, Corey Whisson and Loisette Marsh Department of Aquatic Zoology at the Western Australian Museum, and associates Glad Hansen and Hugh Morrison. Anne Brearley was provided with access to the Museum collections and vouchers will be lodged with the Museum.

Data Resources
Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

In addition a field guide of the species identified in this study. This is a work in progress and can be accessed by contacting the Principle Investigator, Dr Black with plans to make it available through the Ningaloo Atlas (http://ningaloo-atlas.org.au/welcome)

Site locations available in Google Earth **.kmz files**
Centers of 36 sites where quadrat samples were taken 2007, 2008, 2009, 2010 and reported on in all the Research Chapters, and where physical data for Research Chapter 8 were collected.

[**WAMSI3.2.2bSites.kmz**]
Corners of 8 sites at northern boundary of Jurabi Sanctuary Zone where data for Research Chapter 9
[**WAMSI3.2.2bJurabi8Sites.kmz**]
Shoreward, southern corners of Transect 1 and some others for areas where *Tridacna maxima* were measured as reported in Research Chapter 4.
[**WAMSI3.2.2bGiantClams.kmz**]

Raw data files in .csv format (plain text files with comma separated values)
Sample (rows) by species (columns) data for each 1-m^2 quadrat (1744 rows x 291 species with 10 sample specification columns.
[**WAMSI3.2.2bQuadratData.csv]**
Lengths of small giant clams (*Tridacna maxima*) mapped at 20 sites (3119 rows x 11 columns including identifying information for each length)
[**WAMSI3.2.2bGiantClams.csv**]
GPS readings as UTM values for locations of transects used to map positions of *Tridacna maxima* (giant clams) (404 rows x 6 columns, including sample identification information)
[**WAMSI3.2.2bTridacnaUTM.csv**]
Physical features of the platforms in three files (32 rows x 13, 11, 10 columns)
[**WAMSI3.2.2bPlatformAttributes.csv]**
[WAMSI3.2.2bPlatformQuantative.csv]
[WAMSI3.2.2bFetchAndContour.csv]
Latitude and longitude of sites
[**WAMSI3.2.2bSiteLatLong**.csv]

Metadata files in .rtf format matched to the raw data files

WAMSI3.2.2bMetadataForQuadratData.rt	WAMSI3.2.2bQuadratData.csv
WAMSI3.2.2bMetadataForGiantClams.rtf	WAMSI3.2.2bGiantClams.csv
WAMSI3.2.2bMetadataForTridacnaUTM.rtf	WAMSI3.2.2bTridacnaUTM.csv
WAMSI3.2.2bMetadataForPlatformAttributes.rtf	WAMSI3.2.2bPlatformAttributes.csv
WAMSI3.2.2bMetadataForPlatformQuantative.rtf	WAMSI3.2.2bPlatformQuantative.csv
WAMSI3.2.2bMetadataForFetchAndContour.rtf	WAMSI3.2.2bFetchAndContour.csv
WAMSI3.2.2.bMetadataForSiteLatLong.rtf	WAMSI3.2.2.bMetadataForSiteLatLong.csv

Images of 32 sites embedded in .rtf file-
Text and images about the 32 sites sampled in 2007 and 2009
WAMSI3.2.2bSitePages.rtf]

Knowledge Transfer

This study is an Inventory and Baseline study and has provided information useful for ongoing research and monitoring of intertidal rocky platform assemblages along with a suite of photos and species information for education purposes. Findings should also be taken into consideration in the management of high access areas and in the next review of the NMP Management Plan regarding Nearshore sanctuary zones.

6.12 Project 3.2.2c: Trophic effects – surveys and experiments

Principal Investigator
Mat Vanderklift (CSIRO Marine and Atmospheric Research)

Research Team
Russ Babcock, Doug Bearham, Geordie Clapin, Kylie Cook, Harriet Davie, Ryan Downie, Mick Haywood, David Kozak, Andrew Limbourn, Nicole Murphy, Fiona Parker, Julia Phillips, Richard Pillans, Damian Thomson, (CSIRO Marine and Atmospheric research), Adriana Verges (Edith Cowan University)

Project Overview
The potential for coral reefs to change from coral dominated communities to a state dominated by macroalgae was first described in the Caribbean following the elimination of grazing urchins by a disease epidemic (Hughes 1994). Since then there has been a growing concern that the removal of grazers, whether urchins or fish, from coral reefs has the potential to reduce the probability or speed of recovery from disturbances such as disease or storms (resilience), and increase their potential to undergo phase-shifts to algal dominated states (Hughes et al. 2007, Mumby 2006). Marine Reserves have the potential to increase the resilience of coral reef communities if they protect exploited grazing fish (Bellwood et al 2006). Marine reserves may provide a net resilience dividend if the levels of mortality of grazing fish due to increased predation inside marine reserves is less than fishing mortality outside (Mumby et al. 2006). However, where grazing fish are not significantly exploited (such as on Ningaloo Reef or the GBR) recovery of exploited predatory species in marine reserves may potentially reduce the biomass of grazers. In either case, it is clear that an understanding of the relative intensity of grazing and its effects on macroalgal biomass is key to sustainable management of natural coral reef ecosystems.

Surveys designed to test the presence of direct and indirect effects of fishing across the three broad habitats (lagoon, reef flat, fore reef) at Mandu Sanctuary Zone were conducted in 2007 and 2008. Additional surveys across >100 km designed to take advantage of natural gradients in abundance of consumers around isolated reef structures to test for their effects on the reef ecosystem were conducted in 2008 and 2009. Surveys focussed on fish, benthic invertebrates, macroalgae, composition of the substrate and the rates of key ecological processes (grazing, predation).

Objectives
The objectives of the surveys described in this report were to provide a robust quantitative assessment of whether evidence exists for direct (i.e. mortality due to fishing) and indirect (i.e. changes in interactions among species due to reduced abundance of fished species) ecological effects of fishing in the Ningaloo Marine Park. As such the project has direct relevance to the following outputs from WAMSI Node 3.2:

- Measures of the effectiveness of previously established sanctuary zones for protecting exploited subtidal fish and invertebrate populations;
- Assessment of whether there is consistent evidence for trophic cascade effects in previously established sanctuary zones;
- Experimental assessment of potential for indirect effects of fishing on lagoonal and shallow water ecosystems;
- Assessment of adequacy of sanctuaries for exploited species and related ecological effects; and

- Baselines for future assessment of the importance of zone size, age, configuration, location on effectiveness for protecting biodiversity in subtidal and intertidal communities.

Materials and Methods

Underwater visual surveys were conducted in April-May 2007 and February-March 2008 to measure key biota (fish, benthic invertebrates, macroalgae, corals) in lagoon reef flat and reef slope habitats. Surveys were undertaken in both recreation and sanctuary zones (Figure 1).

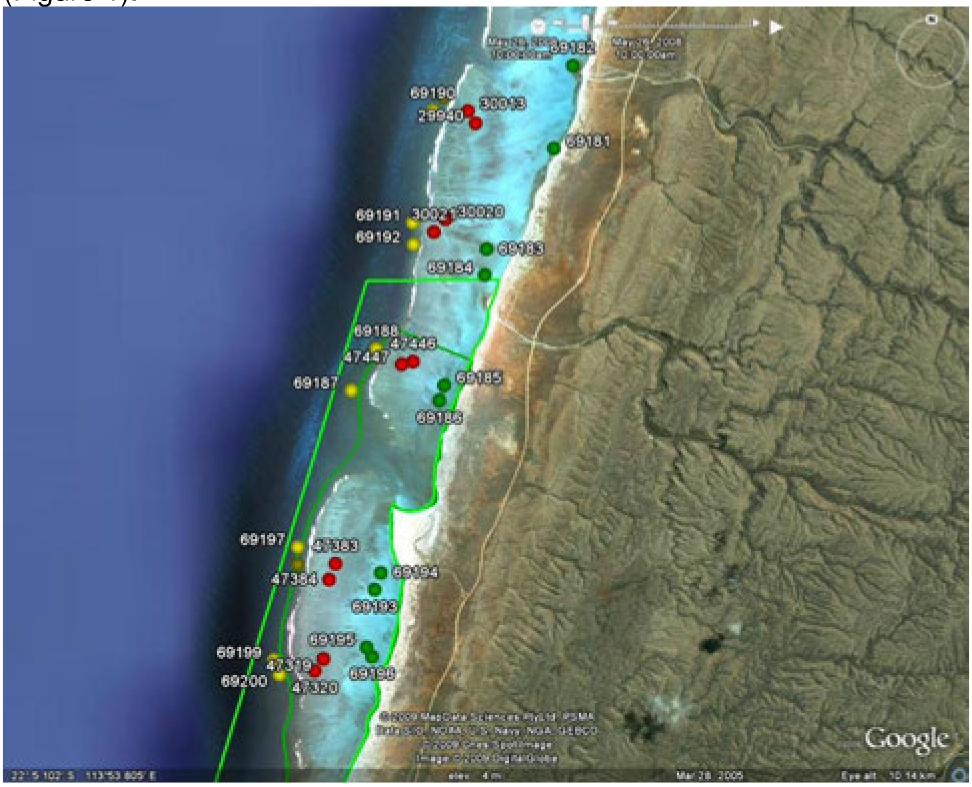

Figure 1. Sites selected for surveys of ecological effects of fishing within lagoon, reef flat and reef front habitats at Mandu Sanctuary Zone. Green dots indicate lagoon sites, red dots indicate reef flat sites and yellow dots indicate reef slope sites. .

The surveys recorded data on fish sighted, including number and estimated size and mobile benthic invertebrates (e.g. echinoderms (sea urchins, sea stars) and molluscs (trochid gastropods, *Drupella*, and tridacnid clams) including number and estimated size. Macroalgae was sampled from 1m^2 quadrats and benthic community (mainly coral) was surveyed using photographic line transects. The three-dimensional relief of each transect was also quantified. Relative predation and grazing activity on the reef was quantified using tethered invertebrates (*Drupella cornus* and *Echinometra mathaei*) and macroalgae.

Key Findings

The total biomass of fish was significantly higher inside the Mandu Sanctuary Zone than in adjacent fished areas to the north. This was also reflected by significantly higher biomass of parrotfish (family Scaridae), and a near-significantly higher biomass of wrasses (family Labridae). The biomasses of emperors (family Lethrinidae) showed a near-significant interaction between habitat and management zone – reflecting that the biomass of emperors was higher inside the sanctuary in the reef flat habitat. None of the other major families of fish showed patterns of biomass related to the sanctuary zone. These results confirm and extend the patterns reported previously from project 3.2.2a and are likely to reflect direct effects of fishing on emperors (in particular *Lethrinus atkinsoni*) and large wrasses.

No overall differences were recorded in the biomass of benthic invertebrates or macroalgae, suggesting that indirect effects of fishing are weak. The lack of patterns in overall biomass was reflected by an absence of differences in rates of grazing on tethered macroalgae, and inconsistent patterns in rates of predation on tethered invertebrates.
The biomass of all the major taxonomic and functional groups surveyed was strongly related to the measures of the structural complexity of the habitat (rugosity). This relationship was typically either linear (high biomass at high complexity) or hump-shaped (high biomass at intermediate complexity). These results extend the importance of habitat complexity shown in previous surveys (project 3.2.2a) to other habitats, and indicate that measures to protect habitat complexity should be an important management goal.

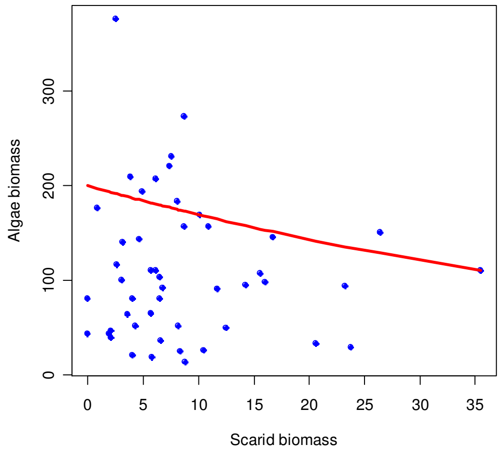

Figure 2. Relationship between biomass of parrotfish (Scaridae) and biomass of algae. Red line shows fits of quantile regression.

The biomass of algae was related to the biomass of parrotfish (Scaridae), but not in a simple linear relationship – rather, the maximum biomass of algae was negatively correlated with the biomass of parrotfish (Figure 2). This suggests that, while other factors are also likely to influence the biomass of algae (so that the biomass of algae is sometimes low even where there are few parrotfish), the presence of abundant parrotfish helps maintain low algae biomass. The generality of this relationship, and its significance for maintenance of coral reef diversity and function, warrant further investigation.
The biomass of fish, and rates of grazing on tethered algae, were significantly higher adjacent to, than distant from (60 – 120 m), isolated reef structures. Conversely, the biomass of macroalgae was significantly lower adjacent to these structures. The low biomass of macroalgae around these structures created patterns that were visible from aerial images (Figure 3). Analyses of these images allowed location of 136 such patterns with an average area of 3.1 ha (+/-0.32 SE: range 0.5 - 24.8). The inverse patterns of biomass of algae and rates of grazing, combined with the patterns of aggregation of fish around the reef structures, indicate that the patterns are maintained through the grazing activities of large herbivorous fish. The ubiquity of the patterns on hard lagoon substrates throughout NMP further suggests the widespread ecological importance of herbivory. This observation, combined with observations of lower biomass of one key group of herbivorous fish (parrotfish) in fished areas, further indicates that measures to protect rates of grazing should be an important management goal. The current lack of understanding of the mechanisms underlying the lower biomass of parrotfish in fished areas should also be the focus of future research effort.

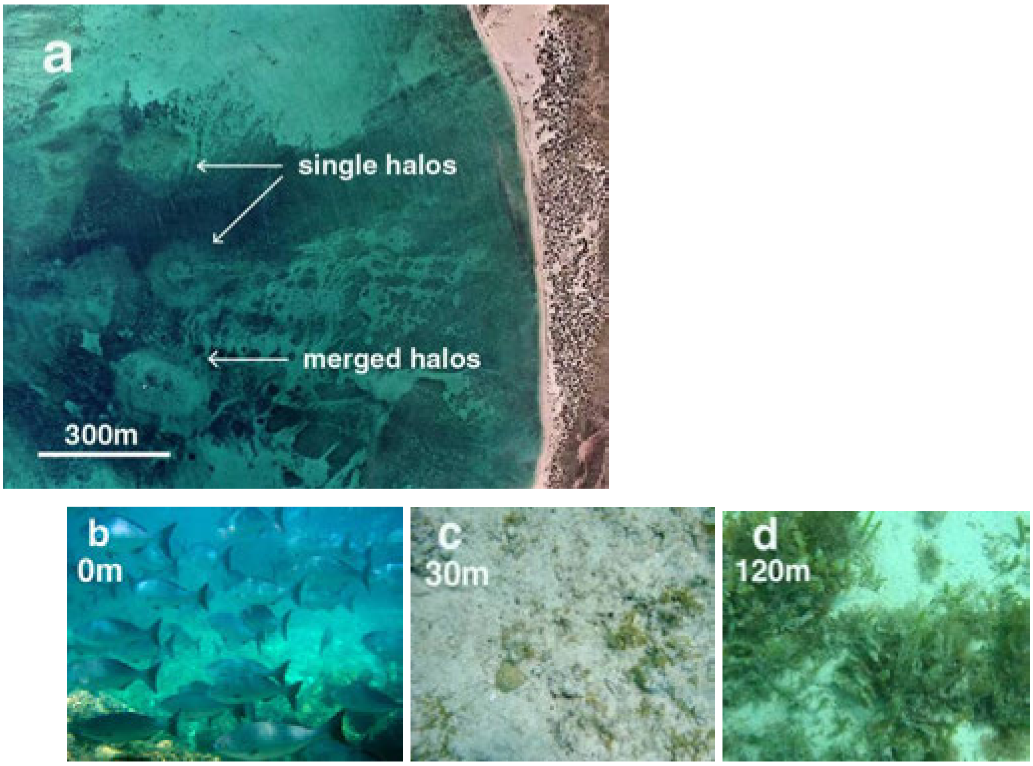

Figure 3. (a) Aerial photo of a 1.0 km section of the Ningaloo Reef lagoon with grazing halos evident around coral bommies (Landgate Skyview series). (b). A school of *Kyphosus sydneyanus* individuals observed feeding at the edge of a patch reef. (c) Substrate 30m from patch reef. (d) Substrate 120m from patch reef.

Management Implications

Detailed surveys of reef flat habitats showed that there were significant effects of protection on overall fish biomass. Trends in biomass of predator functional groups (emperors, and large wrasses) were weak but consistent with significantly higher biomass and densities of these groups reported in other recent studies. This suggests that fishing is having a measurable effect on the biomass of these ecologically important species in NMP.

The ubiquity of the relationships between fauna (fish and invertebrate) biomass and the structural complexity of the habitat confirm that structural complexity is a key feature of the reef habitat, and measures to protect this should be a management priority.
Herbivorous fish, especially parrotfish (Scaridae), were more abundant inside sanctuary zones than outside, presumably as an indirect consequence of higher target species biomass. The mechanisms that cause this pattern remain unclear. Higher grazer biomass in sanctuary zones may be evidence of a novel mechanism through which reef resilience is maintained. In order to capitalise on this as a potential focus for management actions we need to better understand the mechanisms underpinning the patterns, or risk unintended outcomes.

The activities of grazing fish maintain areas of low algal biomass that encompass a large proportion of hard substratum in the lagoon. There appears to be a critical level biomass of grazing fish above which macroalgae biomass is unable to reach high levels. Qualitatively, surveys reported here and in project 3.2.2c (Verges et al) suggest that if grazer biomass decreases below approximately ~800-1200 kg ha^{-1} (i.e. equivalent to ~10-15 kg per transect) there may be corresponding increases in macroalgal biomass. The methods, reference sites, focal species and above information should inform long- term monitoring protocols for NMP.

Acknowledgements
We would like to thank staff from the Department of Environment and Conservation, Exmouth District, and the Yardie Creek Caravan Park for logistical support.

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Mumby PJ, Dahlgren CP, Harborne AR, Kappel CV, Micheli F et al. 2006. Fishing, trophic cascades, and the process of grazing on coral reefs. Science 311:98-101

Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Data collection was carried out by diver surveys, visual counts, biomass sampling and experimental manipulations (tethering) to assess predation and grazing rates. Data were collected annually from both sanctuary and non-sanctuary areas at broad scales along the length of the reef (more than 400 sites sampled in 2006 and 2007) as well as more intensively for a subset of the areas sampled.

Data is currently in the form of ACCESS databases and is available through CSIRO MARLIN and metadata available at iVEC

Knowledge transfer

This project is a Process and Baseline study providing baseline data on biodiversity and the process of herbivory. It is useful to managers assessing the effectiveness of management zones as well as the need for additional conservation measures to preserve habitat complexity. Information relevant to long-term monitoring of these biodiversity groups and integral process along with new research questions to better understand these relationships is also provided.

6.13 Project 3.2.2c: Trophic effects through herbivory at NMP.

Principal Investigator
Glenn Hyndes (ECU)

Research Team
Adriana Verges, Peter Michael, Christopher Doropolous (ECU) and Mathew Vanderklift (CSIRO)

Project Overview

The NMP revised Management Plan in 2005 identified the diversity of fish found within NMP as a key ecological value, and fishing (particularly recreational) as a major pressure on this value. As a consequence, the management plan established an objective to "ensure *the species distribution and abundance of finfish species are not unacceptably impacted by recreational and commercial fishing*". A spatial management strategy has been established using a range of management zones, including sanctuary zones, to achieve this objective. To inform management of the park, a large research programme was established within WAMSI. The current study was nested in "Project 3.2: Biodiversity assessment, ecosystem impacts of human usage and management strategy evaluation" of WAMSI Node 3.

Coral reefs are diverse ecosystems which host abundant populations of consumers and algae in spatial mosaics of both coral and algal dominated habitats. A key ecological process in coral-reef ecosystems is herbivory, which has direct effects on macroalgae and indirect effects on corals by influencing the outcome of coral-algal competition. Despite high diversity and abundance of nominally herbivorous fish, recent studies indicate that only a small subset of taxa are capable of removing dominant macroalgae once these become established. This limited functional redundancy highlights the potential vulnerability of coral reefs to disturbances that result in an increase of algal abundance, and stresses the need to assess the functional role of individual species of herbivores. Further, changes to species assemblages, including the distribution and abundance of herbivorous species can have follow on consequences to coral-algal competition and reef health.

Due to the importance of herbivores in coral-reef systems, this study focused on characterising and quantifying the process of herbivory in the NMP.

Objectives

The broad aim of this study was to gain an understanding of the trophic effects of herbivores and their varying roles in NMP, as well as determining the variability in the consumption of food sources at different spatial scales throughout the park, providing critical information for spatial management. The study encompassed a range of sub-studies related to herbivory using multiple descriptive and experimental approaches, detailed in Verges et al. (2011).

Materials and Methods

We used macroalgal tethers, in combination with video cameras, to determine the species identity of the key herbivorous fishes and consumption rates (Figure 1). The study also employed stable isotopes to assess the sources of production for fish and invertebrate herbivores, as well as recruitment plates in manipulative experiments to assess the role of herbivores in influencing recruitment of algae. Sampling was undertaken across 5 regions within NMP to look for spatial differences in herbivory.

Figure 1. Diver deploying a video camera focused on a *Sargassum* tether to the right of the photo.

Key Findings

This study has provided key information relating to species diversity, abundance, size composition and distribution for herbivorous fish at NMP. The biomass and species composition of roving herbivorous fishes varied among the five regions examined (Bundegi, Mandu, Point Cloates, Maud and Gnaraloo). While 23 different fish species were observed consuming macroalgae, only seven species (*Naso unicornis, Kyphosus sp., K. vaigiensis, Siganus doliatus, Scarus ghobban, S. schlegeli* and *Scarus* sp.*)* together accounted for 95% of the observed bites across five regions (Figure 2). Of these species, three taxa were identified as the most important in consuming macroalgae (*Sargassum myriocystum*): *N. unicornis*, *Kyphosus* sp. and *K. vaigiensis*. These results were supported by stable isotope analyses that incorporate nutrients from food sources over far longer periods than those examined using the assay approach.

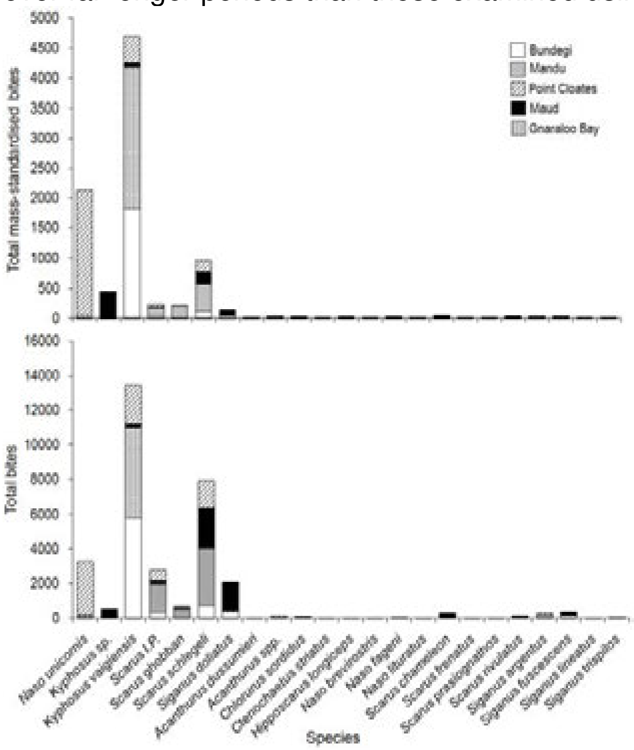

Figure 2. The total number of mass-standardised bites, and raw bites, taken by fishes on the transplanted *Sargassum* assays across five regions of the Ningaloo Reef.

The structurally complex coral-dominated outer reef and reef-flat habitats were characterised by the highest biomass of herbivorous fish and greatest levels of herbivory (based on *Sargassum* assays), compared to lagoon habitat (Figure 3). There was also a high degree of variability in grazing rates among regions separated by hundred of kilometers in the marine park, with different species responsible for macroalgae removal among those regions.

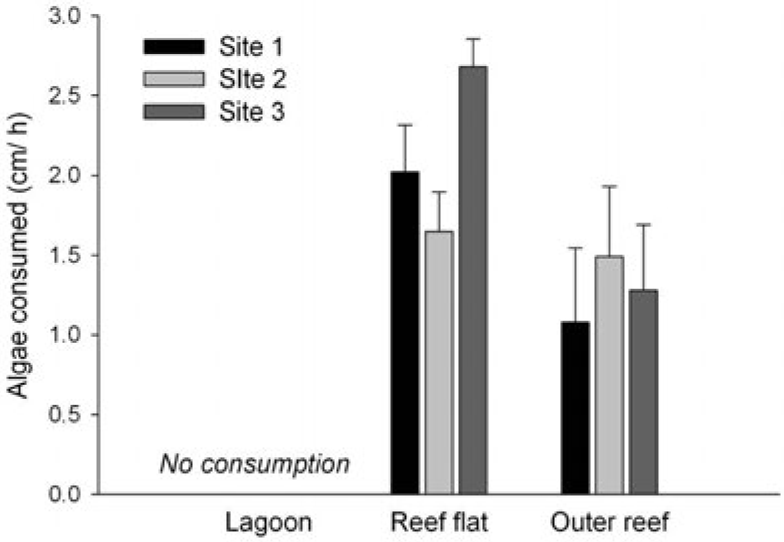

Figure 3. Length of *Sargassum myriocystum* lateral branches consumed per hour (mean + SE) at lagoon, reef flat and outer reef habitats at each of the experimental sites.

A direct comparison of herbivory between different coral-reef systems, indicates that Ningaloo Reef is a comparatively pristine system. Comparison between Keppel Islands in the Great Barrier Reef (GBR) on the east coast of Australia and Ningaloo Reef, showed differences in the diversity of the species observed feeding and the species composition of roving herbivorous fishes. In NMP, 23 species were observed biting on *Sargassum*, compared with just 8 in the Keppel Islands (Figure 4). The larger number of species feeding on macroalgae in NMP suggests that there may be higher functional redundancy among macroalgae consumers in this system, however, a large proportion of herbivory was dependent on only a few species in both regions.

There were high levels of variability in the importance of different food sources across both habitats and regions for some consumers (e.g. *Siganus* spp.), but consistency for other species (e.g. *Naso unicornis, Kyphosus* spp.), which is likely to reflect shifts in food source availability or feeding preferences.

Herbivory had an equally strong effect on the community composition of algal recruits in the lagoon and reef-flat habitats, despite the reef flat hosting a herbivorous fish community that is an order of magnitude greater in terms of biomass than the lagoon, which is characterised by younger and smaller fish, e.g. *Scarus* initial phase. Differences among habitats in algal biomass were strongly influenced by season. Lagoon habitats only have higher biomass than reef flat habitats during part of the year (late summer/ early autumn). Apparent habitat differences in community composition of algal recruits were in fact driven by the presence of damselfish, which were only present in some of the treatments within the reef-flat (but never in the lagoon).

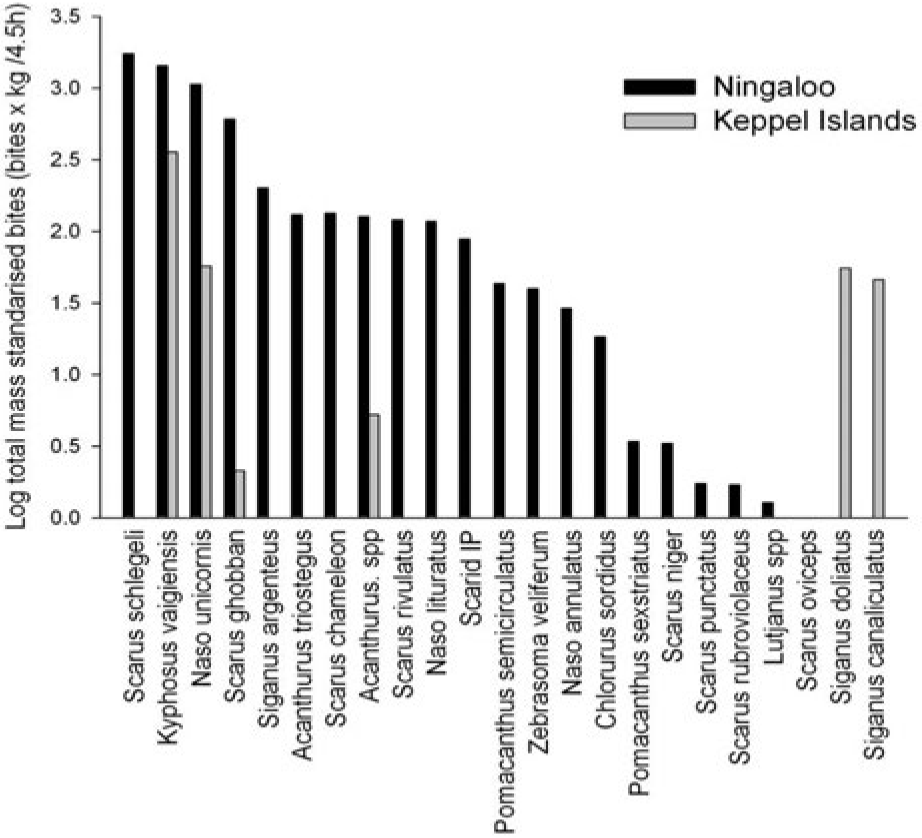

Figure 4. Total number of mass standardised bites (log transformed) taken by of the herbivorous fish assemblages feeding in each region over 4.5 hours (n = 6).

Our results indicate that total herbivore biomass is a poor indicator of potential consumption of dominant macroalgae, and its use in implying trophic effects could lead to erroneous conclusions. Only a few of the 23 roving herbivorous species play a significant role in macroalgae removal. We found the kyphosid species to have a dominant role in removing macroalgae, but there is variability in their abundances across regions. Furthermore, *N. unicornis* is also an important species for the removal of macroalgae. While these herbivore species are not targeted by fishers, they are likely to be susceptible to changes in the abundances of higher order predators such as sharks, which have been shown in project 3.2.1 to be affected by fishing activities leading to potential trophic cascades. Furthermore, these grazers are also likely to be susceptible to non-fishing human disturbances (e.g. oil spills and coral damage) and natural disturbances that affect coral structure (e.g. cyclones).

Management Implications

The consumption of macrophytes by herbivores is a particularly important ecological process in coral reefs that supports intricate food webs and strongly contributes to the resilience of these systems following disturbances such as cyclones or bleaching events. This study has provided data on the relative consumption rates of macroalgae and the relative role of different herbivores at different spatial scales in the NMP. It has provided valuable data on the key role of a few fish species in removing dominant macroalgae from this coral-reef system, and on the variability of consumption rates across habitats and regions. These data will support managers in decisions about the management framework for NMP as well as the development and implementation of a robust monitoring program. The following specific points should be taken into consideration in that regard:

- Although herbivorous fishes are not presently targeted by fishers in NMP, this trophic group is increasingly being targeted for exploitation elsewhere. We have provided quantitative data that can be used to support potential management plans aimed at protecting specific herbivorous fish species (Kyphosus spp and Naso unicornis) from exploitation on the basis of their critical role for promoting coral-reef resilience.
- Herbivory is a dominant mechanism that influences the abundance of fleshy macroalgae when recruitment space is equal in the lagoon and reef-flat habitats, but its influence is greatest with increasing habitat structure. Zoning needs to consider the movement of key herbivores within and across habitats when determining boundaries of management zones.
- Variability in grazing rates across NMP, and the species responsible for grazing, indicates that any future monitoring of key species needs to take place over different regions of the marine park.
- Monitoring the biomass of *Naso unicornis, Kyphosus* spp. inside and outside sanctuary zones will provide crucial information of the potential influence of zoning on macroalgae herbivory in the NMP, as well as a region's ability to recover from disturbances that enhance macroalgal production.
- Quantitative data on rates of herbivory from our studies can be incorporated into broad-scale fish density data from other projects to model the effects of disturbances and changes in management strategies on herbivory, and potential effects to the system as a whole.
- Research is needed to further investigate the potential for indirect ecological effects and trophic cascades through the removal of higher order predators (e.g. sharks) in the NMP.

Acknowledgements

We are grateful to the team of staff and volunteers for their tireless support in the field and/or laboratory: A. Bostock, E. Crochelet, R. Czarnik, F. Dalaine, J. Eyres, M. Haywood, K. Inostroza, P. Kiss, R. Larsen, A. Lemmon, I. McLeod, P. Michael, N. Millar, T. Minutoli, V. Mocellin, A. Richards, J. Santana, D. Thomson, F. Vitelli and co-authors. We thank J. Tanner for the stable isotope analyses, and J. Ortiz for statistical advice and thoughtful discussions on aspects of the study. We also thank the co-authors of the chapters within this report for their discussions and other contributions: D. Abecasis, D. Bellwood, S. Bennett and P. Michael. Additional funding through ECU and D. Bellwood at James Cook University allowed the cross continental comparison.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Video footage of grazing rates and species identity, forming a significant part of this project, has been provided to iVEC. As data summaries are completed for publication, data will be added to iVEC submissions.

Knowledge Transfer

This is a Process study providing information on the ecological process of herbivory and potential for trophic effects at NMP. It will be useful in supporting management framework decisions regarding the take of herbivorous fish and in the design and implementation of long-term monitoring of herbivorous fish and their role in reef health.

6.14 Project 3.2.2e: Assessing zone adequacy using fish tagging and acoustic receivers.

Principle Investigator
Russ Babcock (CSIRO Marine and Atmospheric Research)

Research Team
Richard Pillans, (CSIRO Marine and Atmospheric Research), Glenn Hyndes and Jason How (Edith Cowan University)

Project Overview
Understanding fish movement and home range is critical for effective marine reserve design as the size of the reserve and the mobility of the fish populations will influence the degree of protection offered to species. In a network of reserves along a narrow band of coastline (such NMP) fish that move large distances, either along the coast or offshore, may not be adequately protected. Similarly, if sanctuary zones do not include sufficient amounts of key areas of habitat used by particular species, they may not achieve sufficient levels of protection.

Until recently there has been little or no data on the movement patterns, spatial distribution and habitat utilisation of commercially and recreationally important fish species within NMP (or virtually anywhere in the country for that matter) at scales relevant to the marine park zoning design. As a result, the effectiveness of the size and spacing of existing sanctuary zones, in terms of protecting these species from exploitation, is uncertain. Conversely, the movements also have important implications for so called spill-over of fish from no-take areas to fished zones. Multiple-use management of marine ecosystems must achieve a balance between the competing objectives of conservation and resource utilization. Increasingly, numerical models are used to assist managers in trying to achieve these objectives, however these models will only be useful if they incorporate realistic assumptions and understanding of habitat use and ranges of movement.

Acoustic tracking of tagged fish is the best method for obtaining this data on scales relevant to the ecology and management of the species of interest (i.e. major fishing target groups: *Lethrinus nebulosus, Coris aygula; Carangoides fulvoguttatus. Kyphosus sydneyanus Epinephelus rivulatus, E. multinotatus, E. tauvina, Plectropomus leopardus and Variola louti).*

Objectives
This study sought to determine how the movement patterns, life history and habitat use of key fished species interact with design of sanctuary zones to determine zone effectiveness.

Materials and Methods
A permanent receiver array was established at NMP as part of the Australian Integrated Marine Observing System (IMOS) co-managed by the Australian Animal Tracking And Monitoring System (AATAMS). The array was designed to cover a full range of habitats such as mangrove inlets, beach rock reefs, lagoon, bommies, reef flats, reef passages and reef slopes and encompasses both sanctuary and recreational fishing zones (Figure 1).

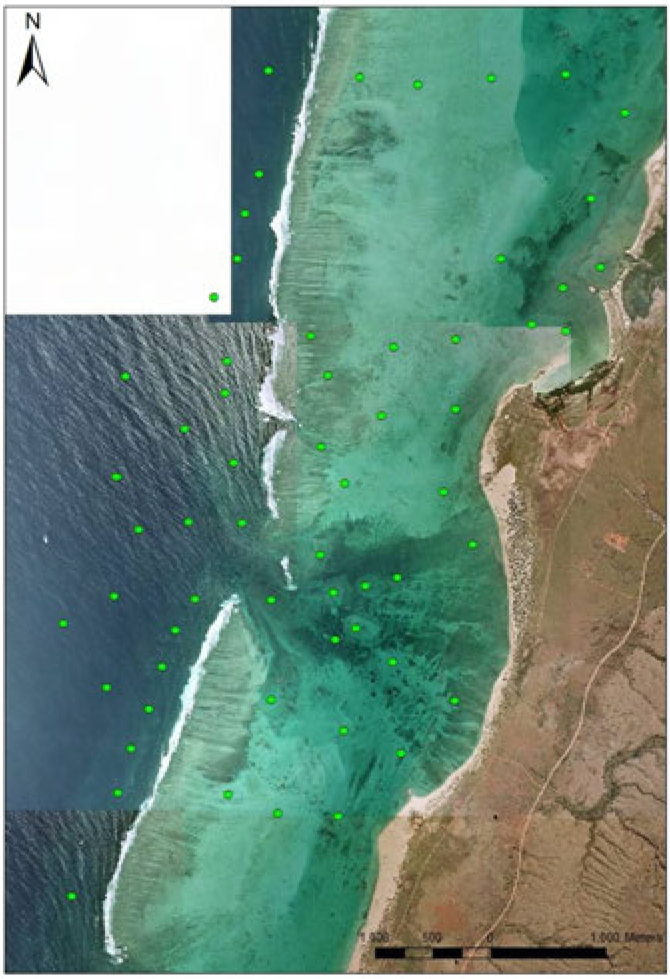

Figure 1. Detail of the small scale array at Mangrove/T-Bone Bay. Locations originally planned were varied as necessary at the time of deployment due to local conditions of depth or locally bathymetry (e.g. bommies or rock bars may block signals in some locations).

We implanted acoustic tags into a number of fish, captured by hook and line and subsequently released at point of capture. Species selected for the study included: spangled emperor (*Lethrinus nebulosus)* based on their abundance and role as key target species for recreational fishers, (*Carangoides fulvoguttatus*) which is likely to be quite mobile but still reef associated to a degree, black wrasse (*Coris aygula)* an invertebrate feeder with limited movement, and an herbivore (*Kyphosus sydneyanus)* a schooling species with unknown movement patterns. In addition, a range of grouper species (*Epinephelus rivulatus, E. multinotatus, E. tauvina, Plectropomus leopardus* and *Variola louti*, Serranidae) were also tagged. Fish tagged were of a range of sizes, with the aim of incorporating any ontogenetic shifts in habitat or size of activity centre in the observations.

Data were regularly uploaded off the receivers (at least at 6 month intervals) and uploaded into a database. This information was used to estimate core habitat area and relative use of space. Further details on methodology can be found in Babcock et al (2011).

Key Findings

This study has found that the habitat utilization areas of most of the species tracked is smaller than was assumed prior to this study and it appears that most of the sanctuary zones within NMP are of a size adequate to protect a significant proportion of the fish populations, though this will vary with each species (Figs. 2,3). For example the mean diameter of core habitat areas for a range of groupers is less than 1 km, and for spangled emperor 2.5-3-5 km. While the majority of sanctuary zones are larger than this, the linear extent of sanctuary zones in the northern part of the park is approximately 2.8km, about the same as the size of the area encompassed by the movements of an individual spangled emperor. Movements of other species such as gold spot trevally (*Carangoides fulvoguttatus*) are larger than this however and it should be noted that smaller sanctuary zones may not be adequate to protect such species. Further, the sizes of sanctuary zones for some habitats, such as reef slopes, may be too small relative to the areas encompassed by the movements of the species that inhabit them. Planning for future sanctuary zones could incorporate these measurements into modelling approaches to provide a basis for determining optimal size of sanctuary zones.

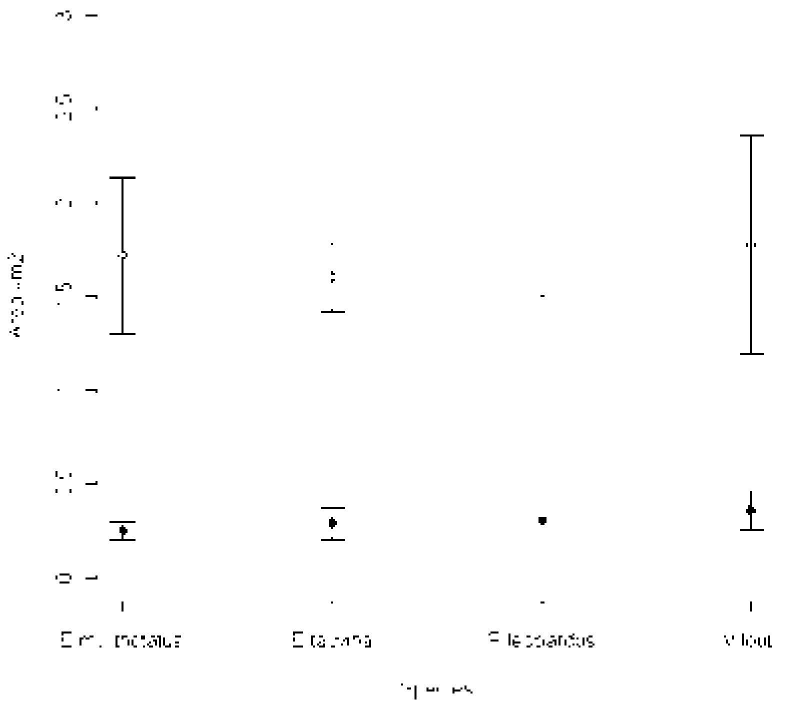

Figure 2. Serranid home ranges. Mean 95% activity kerneal (open circle) and mean 50%activity kernel areas (filled circle) ± SE

Certain habitats appear to be of particular importance for feeding, resting and movement between habitats. Most of the species tracked made extensive and frequent use of the reef passage for travel between the lagoon and the reef slope. This study also found that spangled emperor made extensive use of nearshore areas, a behaviour that might render them more susceptible to beach fishing. Reef passages and channels are well represented in NMP management frameworks with an estimated 53% of major reef passages within the park included within sanctuary zones.

Both emperors (Lethrinidae) and groupers (Serranidae) are known to spawn in aggregations at sites with particular characteristics. Spawning related behaviour of spangled emperor was inferred to take place over a period of up to two months in November-December based on movements of larger individuals. It appears that spawning takes place offshore but the precise locations of spawning are not known. Similarly there was little or no suggestion of spawning aggregations from the records of serranid fishes observed within the array. Such information may be used in reviewing the existing zoning or in the zoning of other parks in northwest Australia.

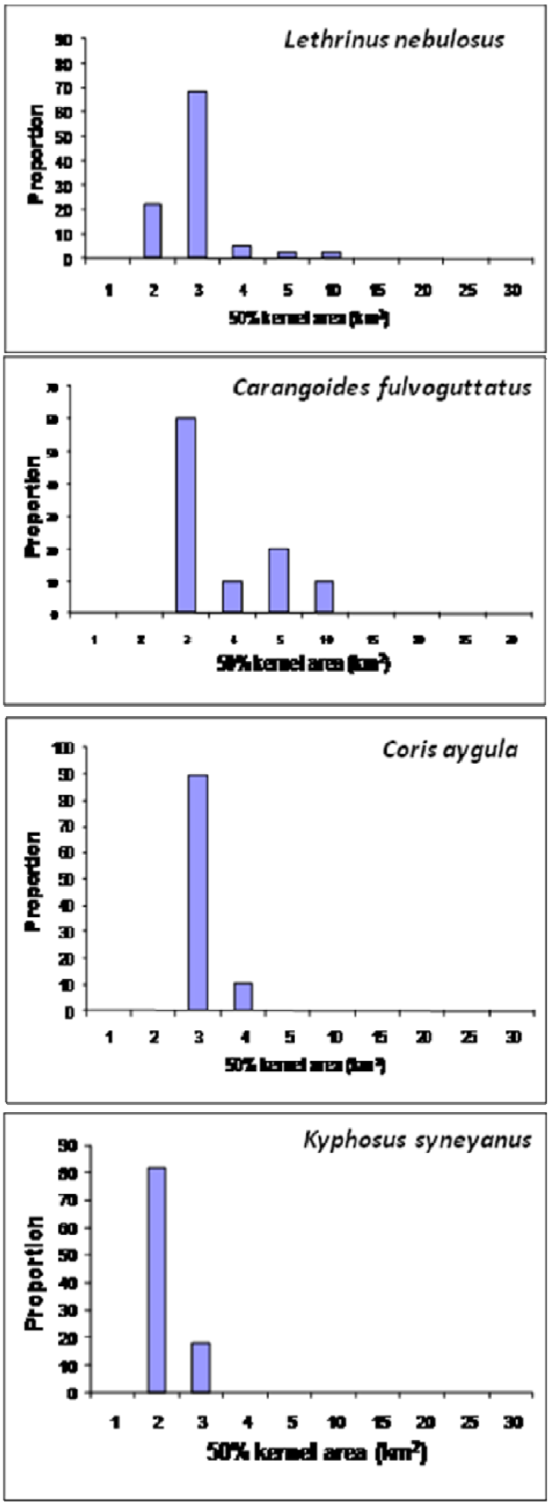

Figure 3. Cumulative proportion of 50% activity kernel area for species studied at Ningaloo Reef Mangrove Bay array.

Additional observations have been made for a range of species but the number of individuals tagged is as yet too small to enable us to make valid inferences about the species' behaviour on which management decisions could be made. These observations are valuable however in that they can be added to over time to build up an understanding of the habits and habitat use of a wide range of fish species, sharks and rays, as well as marine reptiles and mammals and their interactions with human uses of the park.

Management Implications

These findings have some important implications for management that can be readily employed in decision making processes. For example, while lagoon and reef flat areas are well represented within the sanctuary zone system of NMP however many shoreline areas within sanctuary zones are exposed to fishing because of special purpose shore based angling zones. These zones may put populations of spangled emperor within such sanctuary zones at disproportionate risk of capture.
Management should consider removing provisions that allow shore based fishing from coastal sanctuary zones to provide adequate protection for this important species. Further the information on range size is relevant to zoning plans and should be incorporated not only into reviews of NMP zoning, but also into the modelling exercises undertaken in other coral reef areas to plan marine park design.

This project also identified several areas of ongoing research that would continue to inform and improve management for these key fish species. For example, it is important to improve our knowledge of the timing and location of spawning behaviours of key target fish species such as *Lethrinus nebulosus* and groupers in NMP so that these sites may be adequately protected.

Further, a significant knowledge gap exists in terms of our understanding of the movements of fish at scales larger than the Mangrove Bay array. This gap has significant implications for the understanding of connectivity among the sanctuary zones in NMP and is a key area for further research.

Mechanisms should be sought to ensure the ongoing presence of the IMOS AATAMS tracking array and cross-shelf lines at Ningaloo. This study of the adequacy of zoning in the NMP represents a significant investment of resources through the WA Government and WAMSI partners. Additionally there is a major ongoing investment from IMOS to maintain the array. Mathematical models are tools increasingly being used to maximise the ability to understand the implications of how of fish habits and habitat use interacts with human uses of the park in order to assist management. The data obtained in this study provides the opportunity to include fish behaviour in these models, just as the models currently include human behaviour. Population models and other modelling approaches used to inform management of the NMP should explicitly include animal behaviour.

Acknowledgements

We would like to thank IMOS and AATAMS for supporting this work, particularly facility staff Charlie Huveneers and Andrew Boomer, as well as staff from the Department of Environment and Conservation, Exmouth District, and the Yardie Creek Caravan Park for logistical support.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Data collection was carried out through a program of fish capture and surgical implantation of coded acoustic transmitting tags, with data received through a network of acoustic listening stations mainly in the vicinity of Mangrove Bay. Data is currently in the form of ACCESS databases, and also at the IMOS AATAMS website. Metadata can be accessed through the IMOS eMII data portal.

Knowledge Transfer

This is a Baseline study providing information on fish habitat use and behaviour. This information is valuable to improving the management framework for NMP as well as the design of that for other coral reef marine parks. It also points at several important and ongoing research questions for NMP.

6.15 Project 3.2.2f: Coral reef fish habitat associations: implications for MPA management

Principle Investigator
Ben Fitzpatrick (University of Western Australia)

Research Team
Euan Harvey (University of Western Australia) and Russ Babcock (CSIRO Marine and Atmospheric Research)

Project Overview
Fish assemblages are a visually conspicuous component of the biodiversity of coral reefs and have been shown to be highly dependent upon the configuration of habitat (Sale, 2004). The heterogeneous structure of coral reefs influences the distribution and relative abundances of fish at a particular location (Friedlander & Parrish, 1998). For example, specific habitat variables might variously facilitate critical biological processes such as recruitment, refuge, diet and reproduction which will vary by species. In addition, the critical habitat requirements of fishes at different stages in their life histories, or of species within the same genus can differ substantially. Therefore, it is clear that at numerous levels finescale variation in habitat influences species abundance (Doherty et al., 1995).

One of the biggest obstacles to understanding the effect of human impacts on coral reef fish assemblages is inadequate knowledge of the relationship between habitat variability and fish assemblage structure (Sale *et al.*, 2005). Changes in the types of habitats used by fish species throughout their life history makes this task even more complicated (Holland *et al.*, 1996; Babcock *et al.*, 2005). To optimise efficacy of no-take areas it is essential to quantify how species and different functional groups vary across gradients in fine scale habitat structure (Anderson et al., 2006).

Objectives
The goal of this work was to investigate the fine scale habitat associations of coral reef fish assemblages and to determine the effect of human impacts on coral reef fishes in NMP, given the management framework in place. Specific objectives to meet this goal included surveying fish taxa in order to determine:

- How fine scale spatial habitat variation influences the distribution and abundance of coral reef fish.
- Whether there is evidence that protection from fishing influences the overall fish assemblage structure when fine scale habitat variation is accounted for.

Materials and Methods
We used random replicate benthic video transects, Diver Operated stereo-Video (stereo-DOVs) and Baited Remote Underwater stereo-Video (stereo-BRUVs) to sample habitat and fish in the northern region of NMP, including six distinct back reef zones at Mandu and Osprey sanctuary and two adjacent fished locations. From benthic video we derived percent cover of biophysical habitat forming benthos including massive, submassive, branching, tabulate, encrusting, foliose and soft coral, macroalgae, turf algae, coralline algae, sponge, seagrass and sand. From stereo-DOVs and BRUVs we derived the abundance, length, biomass and diversity of fish species which could then be used to derive parameters describing target and non-target groups, trophic groups and the overall fish assemblage. Figure 1 depicts the main concepts explored and the methods used for each element. For further detail see Fitzpatrick (2011).

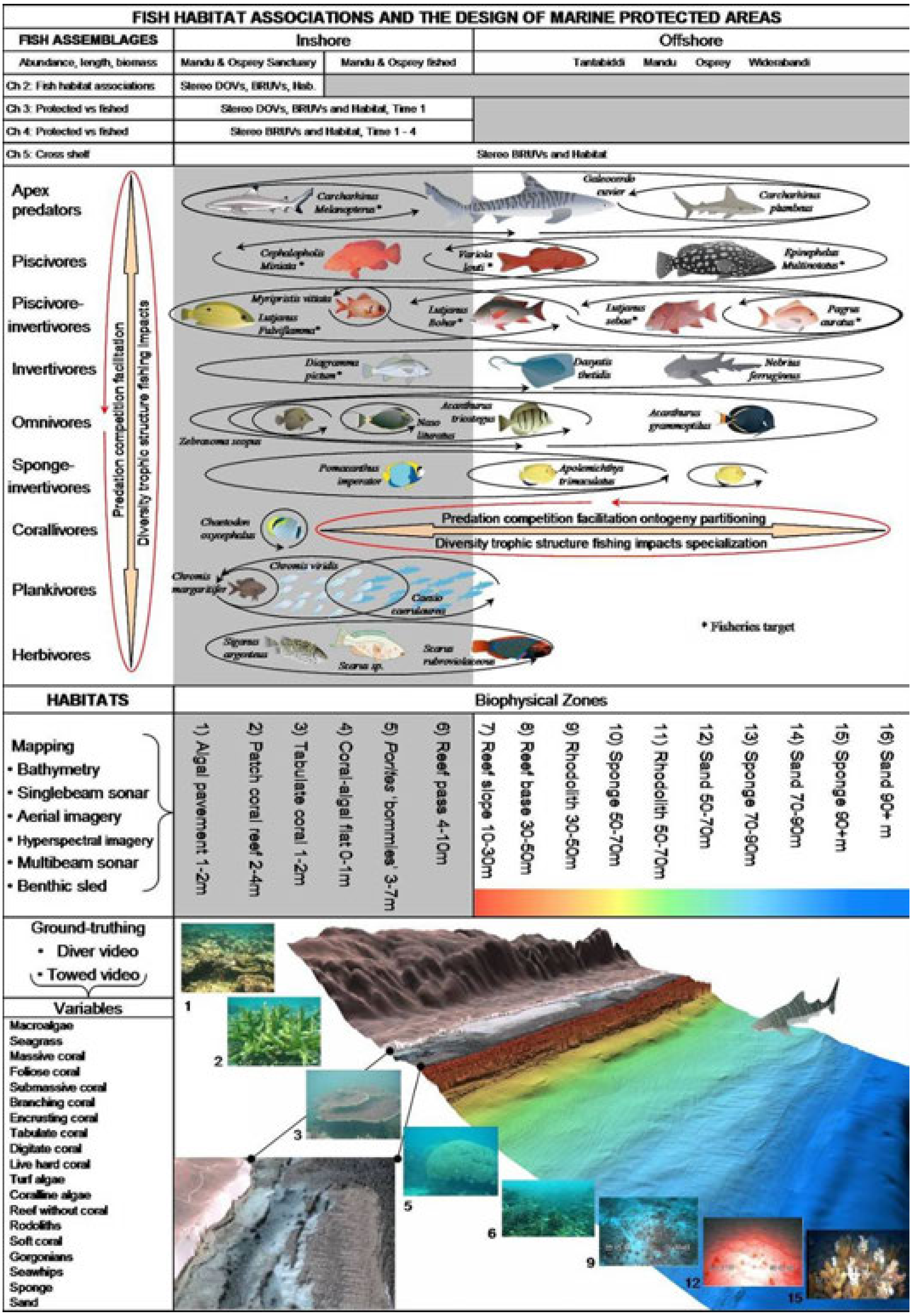

Figure 1 Depiction of the study design and concepts. Extracted from Fitzpatrick (2011).

Key Findings

Significant variation in the reef fish assemblage was driven by variation in habitat. Species richness, overall abundance and the diversity of fish assemblages differed between back reef zones depending upon percent cover of the various benthic habitat types. Abundant species with generalist habitat strategies from different trophic groups drove the majority of the differences, including opportunistic invertivores, herbivores and mobile predatory species from higher trophic levels. Different trophic groups were dominant in different back reef zones with particular groups significantly correlated to particular habitat variables within each. A large proportion of the species were unique to individual zones. A majority of species were associated with three or less habitat zones and were characterised by low abundances.

Protection from fishing accounted for significantly more variation in fish assemblages than that explained by fine scale habitat alone. When compared to adjacent fished sites, target species including serranids, lethrinids, lutjanids and carangids were consistently more abundant and larger. For example, combined, the 22 species of serranids, were 27% more abundant and 19% larger at protected habitats and 17 individuals of the apex predator Grey reef shark (*Carcharhinus amblyrhynchos)* were censused at protected sites compared to zero at fished sites. For the non-targeted fish, protection also accounted for significantly more variation in fish assemblages than finescale habitat variables alone. A number of invertivores were more abundant inside the sanctuary zones. Various herbivores and omnivores were more abundant, and/or larger inside sanctuary zones than at fished sites. However, some of the corallivores were more abundant, but smaller at protected zones and various planktivores were smaller and less abundant at protected sites especially associated with massive porites, where this guild were least abundant and smallest. This was driven by an average increase in the abundance and length of target species and response in non-target species tending to indicate that there are some trophic interactions occurring between fishes (Table 1). Further, both target and non-target species can be more abundant at protected reefscapes through time, consistent with the theory that protected areas can achieve lasting maintenance of fish assemblage structure relative to adjacent fished locations.

This study suggests protection of these fish assemblages has resulted in consistent increases in the average abundance and length of targeted piscivores and piscivore-invertivore trophic groups although target species driving these patterns were different between fished and protected back reef zones. Accordingly protection interacted with back reef zone to account for significantly more variation in non-target fish assemblages in addition to the effects of fine scale habitat variation and location. Responses in non-target trophic groups were dependent upon adult body size with large adult body size species being more abundant and larger at protected habitats, medium bodied labrids, acanthurids and chaetodontids more abundant and often significantly smaller at protected habitats, while small bodied labrids and pomacentrids were less abundant and smaller at protected habitats (Figure 2).

Variable response in abundance of smaller bodied short lived prey species to protection is likely driven by spatial and temporal variable effects of recruitment and highly specific habitat variables not considered in this study (Graham *et al.*, 2003). Whereas larger bodied, longer lived species of scarids, labrids and particularly acanthurids can build up biomass over time despite increasing predation on smaller size classes (McClanahan & Graham, 2005; Mumby *et al.*, 2006). It remains to be determined how stable these trends are through time as the replenishment of various trophic groups are likely to be strongly influenced by seasonally and spatially variable recruitment processes and habitats (Doherty et al., 1995; Friedlander *et al.*, 2007). Nonetheless, stratified sampling across major gradients in habitat to account for its bottom-up effects is essential to adequately assess assemblages for the direct and concomitant top down indirect effects of fishing on overall fish assemblage structure.

Table 1: Direction of response to protection for average abundance and length of trophic groups from stereo-BRUVs and stereo-DOVs. + indicates fish were more abundant or larger at protected sites, - indicates fish were more abundant or larger at fished sites and ~ indicates no difference. Trophic group abundances with spearman correlations to RDA axis 1,2 or 3 >0.25 are highlighted and were significantly different between protected and fished backreef zones. (extracted from Fitzpatrick 2011, which contains fuller details on species).

			Average of abundance							Average of Length (mm)							
	Trophic group	Spearman corr. (RDA Axis 1,2,3)	Overall	Subtidal reef pavement	Porites coral "bommies"	Patch reefs	Tabulate Acropora Flat	Coral algal Reef Flat	Reef pass	KS-test	Overall	Subtidal reef pavement	Porites coral "bommies"	Patch reefs	Tabulate Acropora Flat	Coral algal Reef Flat	Reef pass
Stereo-BRUVs	Target species	**(0.02,-0.39,0.08)**	+	~	+	+	+	+	+	~~	~	~	~	-	~	~	~
	Apex predators	(0.24, -0.06, -0.09)	+	~	~	~	+	+	+	~~	~	-	-	-	+	-	-
	Piscivores	**(0.25, -0.17, -0.14)**	~	~	-	+	+	+	~	++	-	+	-	-	-	+	+
	Piscivore-invert.	**(0.01, -0.3, 0.09)**	+	-	+	+	+	+	+	~+	+	+	+	+	+	+	-
Stereo-DOVs	Corallivore	**(0.38, -0.13, 0.13)**	+	~	~	~	+	+	-	~~	-	~	~	-	-	-	-
	Herbivore	**(0.3, -0.03, -0.06)**	+	+	~	-	~	+	+	++	-	~	+	+	+	-	~
	Invertivore	**(0.13, -0.18, -0.27)**	+	~	+	~	+	~	~	++	-	-	~	~	~	~	-
	Omnivore	**(0.47, -0.05, -0.06)**	+	+	+	~	~	+	~	+ -	+	~	~	~	-	-	-
	Planktivore	**(0.16, 0.19, -0.36)**	-	+	~	~	+	~	~	++	~	-	+	~	~	~	-
	Sponge-invert.	(0.13, 0.06, -0.08)	-	-	-	-	+	~	-	~~	+	+	~	~	+	-	~

This approach has identified potential differences in abundance and length of trophic groups that contribute to critical ecosystem processes and offer potential mechanisms by which protected areas can achieve biodiversity conservation outcomes. It remains to be determined how significant these differences are through time.

Management Implications

This research holds a number of key implications across a range of management strategies relevant to marine protected area management. Overall, though sanctuary zones were found to support fish diversity and abundance, fine scale habitat has a strong influence on fish distribution, including in both assemblages and individual species throughout their life cycle. Further, discrete elements of trophic structure were also significantly associated with different habitats. Fishing and other human impacts affect significantly different elements of coral reef fish assemblages depending upon the benthic habitat. Additionally, this study found that habitats of importance for many shallow coral reef fish extend out across the breadth of the continental shelf. The presence of more abundant and larger target species including many Lethrinids, Lutjanids, Serranids and Carangids, facilitates increased

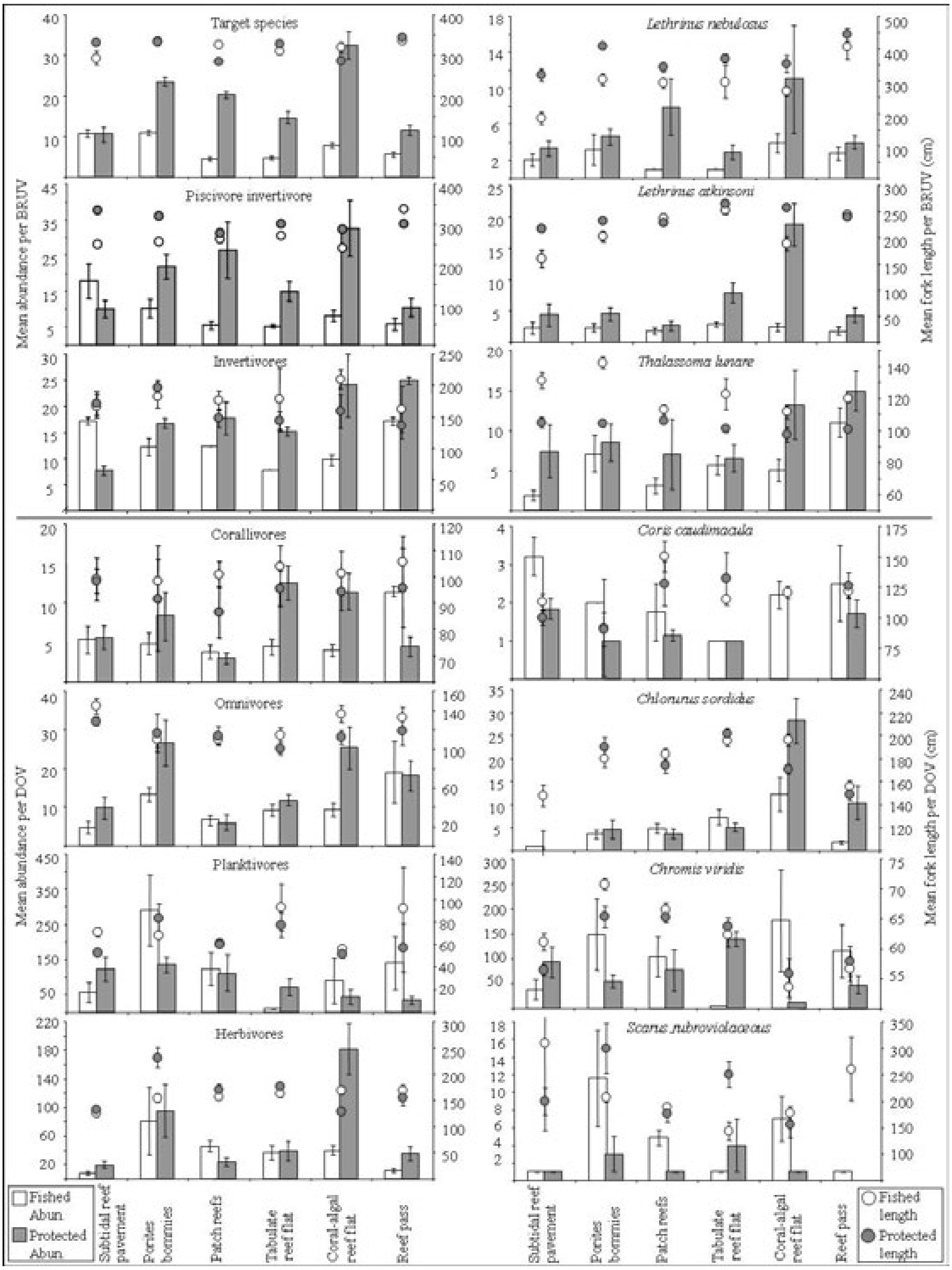

Figure 3: Abundance and average fork length of trophic groups across six backreef zones at protected and fished locations. A number of species were responsible for significant differences within these trophic groups, some of which are shown not necessarily alongside corresponding plots.

abundance of non-target species suggesting a significant mechanism by which marine protected areas can work to protect entire fish assemblages. Thus, the design of coral reef marine protected areas, in particular zoning schemes, must account for variation in benthic habitat and associated variation in fish assemblages to ensure adequate protection for fish assemblages and species throughout their life history as well as important ecological processes.

This study also provides information relevant to further investigation of ecological processes sustaining the coral reef ecosystem of NMP as discrete ecological processes that drive the structure of fish assemblages in one habitat may not apply at another location. For example, fish assemblages associated with discrete habitat types will respond differently and influence their ability to adapt to rapidly changing environments under climate change scenarios.

Finally, this study provides evaluation of useful monitoring tools and baseline data for fish assemblages along with clear evidence that monitoring programs for fish diversity and distribution must take appropriate account of fine scale habitat.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network (AODN) metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Information from fish surveys is stored in a database held at the University of Western Australia with metadata and numerical data held by Ivec and available through the AODN portal (see Data Resources, Section 10).

Knowledge transfer

This study is a Baseline study of coral reef fish assemblages. It provides useful information that should be considered in marine protected area planning (e.g. zoning schemes) as well as research and monitoring programs. The information, in particular on habitat and biodiversity distribution is relevant to other coral reef ecosystems.

6.16 Project 3.2.3: An Evaluation of Management Strategies for Line Fishing in NMP

Principle Investigator
Rich Little (CSIRO Marine and Atmospheric Research)

Research Team
Thébaud, O, Boschetti F, McDonald AD (CSIRO Marine and Atmospheric Research), Marriott R, Wise B, Lenanton R (DoF)

Project Overview
One of the big challenges for contemporary Australian society is the management of competing human uses of, and impacts on, natural and transformed ecosystems. Growing urbanisation, as well as industrial and tourism development have increased the need for government to broker a balance among the activities of many users of the natural and built environment. In meeting this challenge, governments have encouraged an increasingly prominent role for science to provide information and analytical methods for supporting policy and management decisions. In the past the tendency has been to use scientific advice on an ad hoc basis. The growing requirement for scientific knowledge in collective decision-making has prompted scientific research agencies to seek better ways of providing scientific support.

This project explored the effects of managing recreational fishing in NMP. The project used simulation techniques known as Management Strategy Evaluation (MSE) to explore the effectiveness of current management arrangements, and the consequences of a range of alternative management actions, and alternative future scenarios, on the management of a major recreational target species on Ningaloo Reef, spangled emperor (*Lethrinus nebulosus;* Figure 1). The results of the scenarios are examined against the objectives set out by management and other stakeholders in the park.

Figure 1. *Lethrinus nebulosus* (spangled emperor)

Objective
The main objective of this project was to investigate the applicability and benefits of implementing a management strategy evaluation approach to support performance assessment and adaptive management for NMP, in particular for the management of recreationally targeted finfish.

Materials and Methods
The simulation model that was used is known as ELFSim (Effect of Line Fishing Simulator), a decision support software designed to evaluate options for conservation and harvest management. It includes a number of key components: a population dynamics model of target species that captures the full life history (including larval dispersal,

reproduction, development, and habits) of the target species, a model of fishing dynamics that captures the exploitation pattern due to fishing behaviour and a management model that simulates the implementation of management actions. ELFSim was developed for other coral reef fisheries where commercial fishing is the primary fishing activity. In this project we developed a simulation model of recreational fishing dynamics. This model was agent-based, meaning that individual recreational fishing boats were represented in the model, and a range of management measures were tested on the ability to manage these virtual recreational fishers. These measures were based on input from stakeholders. Model output examined the effectiveness of these management measures against a suite of performance indicators and fishery objectives specified by stakeholders in a series of workshops.

Key Findings

The project first evaluated the effects of the current management arrangements operating in NMP (including both the current and previous arrangement of sanctuary zones, bag limit of 4 fish, and fishing effort) on biomass inside and outside sanctuary zones, as well as on catch and catch rates. Marginally less biomass was seen across the entire marine park under the previous sanctuary arrangement compared to the most recent management framework. However, the amount of biomass protected under the current zoning scheme was almost 3 times that under the previous scheme. This means that although more biomass is protected by the current sanctuary zones, fishing effort is more concentrated in the areas open to fishing, resulting in greater depletion of biomass in the recreational areas.

Scenarios were then tested to determine the effect of changes to management arrangements as well as to fishing effort. While removing the bag limits resulted in about a 5% reduction in biomass, an assumed increase in effort was the biggest single factor responsible for reducing the biomass. Combining the two management options compounded the effects such that increased effort and reduced bag limit led to correspondingly higher catches. Doubling the effort however did not double catch, as catch rates declined with increased fishing effort. Overall though, while catches and catches rates could be increased by removing the bag limits, this had a corresponding effect on biomass.

The project also investigated the effects of localised depletion across NMP. Under current management arrangements fishing pressure was greatest, and biomass lowest, around Exmouth, because most of the fishing effort was assumed to be concentrated in this area. Implementation of the current zoning scheme appears to have had a greater effect around Coral Bay than around Exmouth or Tantibiddi Creek in the north. Although bag limits tended to have an effect throughout most of the park, in the vicinity of Exmouth (10-15 nautical miles) bag limits appeared to have little effect mainly because the model assumed there was a high concentration of effort in this area, and any fish discarded would tend to be targeted and taken by other subsequent fishers.

We also evaluated potential future management actions raised at a stakeholder workshop, which included the effect of increasing the sanctuary zones, and restricting shore-based fishing in sanctuary zones. The effectiveness of these alternative management actions in the simulation model were measured against the management objectives of the stakeholders which were classified as either ecological (conservation), social or economic. For example, stakeholders proposed a conservation objective that the spawning biomass in the sanctuaries should be above 75% of pre-exploitation level, and with more than 75% probability. The simulation results showed that restricting shore-based fishing in sanctuary zones consistently had the biggest effect on the spawning biomass in the sanctuaries, and achieved the conservation objective set by the stakeholders. Alternatively, a catch limit that was effectively enforced, while still allowing shore-based fishing in sanctuaries, achieved the stakeholder objective in only 10% of the simulations. Thus, restricting shore-based fishing in sanctuaries was best able to achieve the management objective of conserving biomass in the sanctuaries, while imposing a catch limit (and allowing shore fish to occur) did not.

The other management actions examined included expanding the sanctuary zones, adding an education program, and increasing the compliance monitoring on the fishery (Figure 2). Some management strategies were proposed to combat infringement, and were marginally effective mainly because only a relatively small amount of infringement was assumed in the model, and, without more data on why and the degree to which infringement occurs, it is difficult to compare these to the other management actions.

In general, the results showed that the management arrangements currently operating perform adequately against the range of ecological and social objectives. However, for other management actions, the results showed the inherent trade-off that exists between the ecological objectives and the social objectives. For example, restricting shore-based fishing in sanctuaries did well to achieve the conservation objectives, but did not achieve the social objectives as well as other management strategies. Imposing catch restrictions, increasing compliance monitoring and implementing an education program to reduce infringement also performed well against both social and ecological objectives. However, effectiveness and cost are uncertainties that our analysis did not consider and such factors are likely to be extremely important in any realistic implementation of these management actions.

Lastly, we examined the effect of a selection of management strategies under alternative future scenarios including hypothesized effects of climate, coastal development and developing technology and capacity to find and catch fish. The ability of three management strategies (a “Reference Strategy”, which represents the current management conditions in the park, a strategy that allowed “Increased (fishing) effort” and a strategy that capped catch) to achieve the objectives under a range of these potential future conditions was examined (Figure 3).

The management strategy that was most effective in achieving the objectives was capping the catch. However, allowing fishing effort to increase was best at achieving the social objective of being able to catch large fish. In practice, a combination of strategies like limiting effort, or something else quite novel and resource intensive (like pink snapper tags in Freycinet Estuary in Shark Bay, WA for implementing a recreational TAC), may need to be used for indirectly limiting the overall level of catch of spangled emperor from this sector. Of course such a strategy is also species specific and does not limit potential sustainability risks for other species. It is for this reason that DoFWA uses spangled emperor as an indicator species for the suite of demersal scalefish species in the Gascoyne Bioregion.

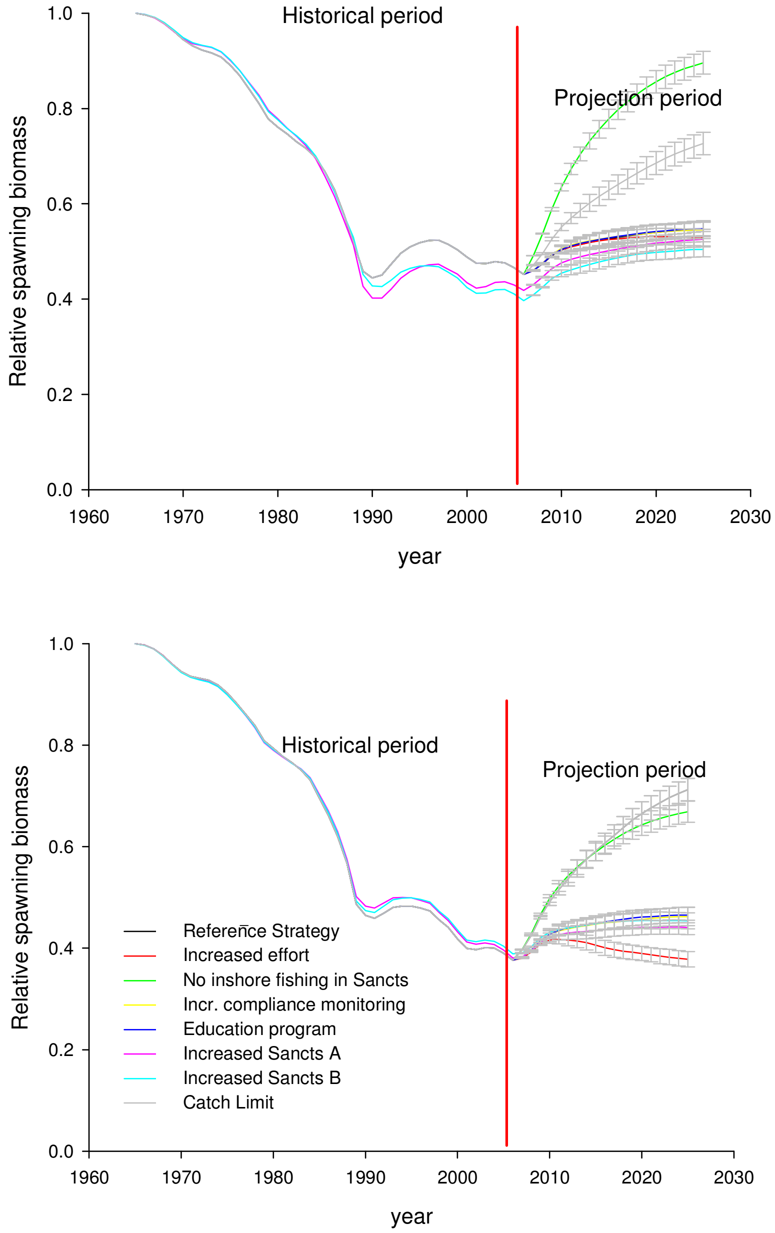

Figure 2 Modelled spawning biomass (average ± SE) in sanctuaries (top) and outside of sanctuaries (bottom) relative to the total unexploited spawning biomass projected, under different management strategies.

Management Implications

The findings of this research have application to the management of NMP in a number of ways. Mainly, the modeling exercises provide evidence of the effectiveness of sanctuary zones and considerations of changes to management in the future should various scenarios play out. For example, sanctuary zones were found to work effectively as a conservation management tool for fish populations and the current sanctuary zone scheme is likely conserving a greater amount of the fish biomass than the previous one. However, sanctuary zones are not as effective when used as a fisheries management tool as the concentration of effort outside sanctuaries counteracts the beneficial population effects created by the sanctuary zones. Thus, when managing for exploited populations (e.g species targeted by commercial or recreational fishers) the use of sanctuary zones needs to be combined with other methods of reducing fishing pressure.

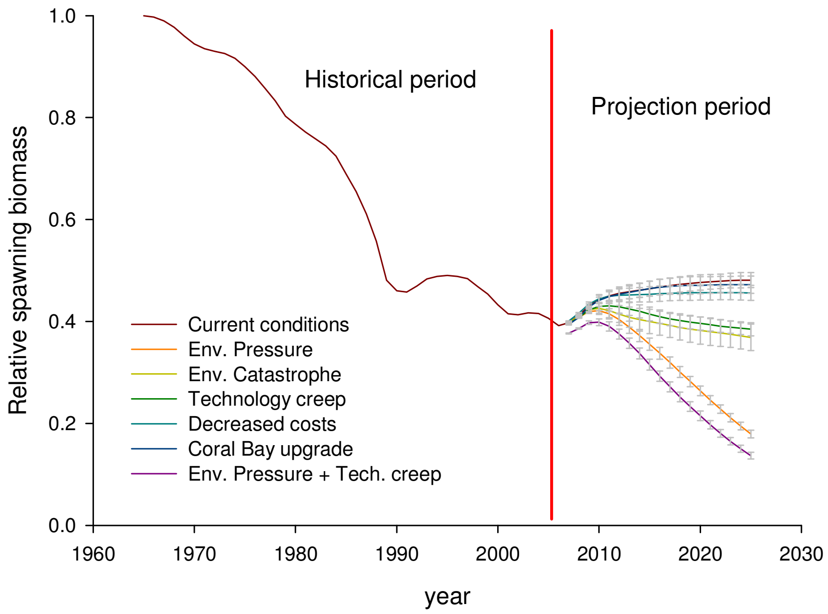

Figure 3 Simulated average spawning biomass (SE) relative to the total unexploited spawning biomass projected under the Reference Strategy management strategy for different future scenarios.

The biggest factor in controlling fishing pressure is fishing effort which can be difficult to control. In particular, the use of bag-limits was demonstrated to provide a small means of control. However, many other potential strategies are available and the effectiveness of these could be explored using the procedures demonstrated through this project.
Review of fishing pressure and effects in NMP need to consider that shore-based fishing inside sanctuary zones was found to have a major effect on the conservation status of the key target fish species in model results. In addition, more information on the actual fishing pressure and effects of shore-based fishing in the sanctuary zones is warranted. In addition, infringement is important and may lead to reduced biomass, particularly in sanctuary zones. It is unknown whether the levels in the model were accurate depictions of reality and a better understanding of compliance across NMP is needed to ensure the maximum effectiveness of the current management regime.

Spawning biomass was a key indicator of the target species status in the model, but in reality it is unlikely that this quantity can be estimated accurately. Alternative indicators of fishing pressure that should be considered for long-term monitoring purposes are CPUE, catches, and the average age and length in the catches.

Fisheries management procedures are currently being developed for the Gascoyne region (Marriot et al 2010). These procedures include assessment models estimating the fishing mortality relative to natural mortality and decision procedures that use these estimates to achieve fishery management objectives. The MSE model developed in this project would provide a valuable means to test this feedback management strategy, possibly showing the accuracy of the assessment method and efficacy of the management procedure.

Making predictions of the future scenarios is difficult everywhere. The scenarios we proposed ranged from broad scale environmental changes across the fishery to small-scale changes of expanding boat ramp capacity. The assumed effects of environmental pressure on the natural mortality had the biggest effect on the fishery. However, the cause of such effects is not well understood and so there is a great amount of uncertainty attached to these results. The small-scale changes associated with expanded boat ramp capacity at Coral Bay did not affect the wider park to a great degree.

Acknowledgements
We would like to thank Beth Fulton and Miriana Sporcic of CSIRO for collaborative efforts. Dan Gaughan (DoFWA) for his input at the start of the project, and all of the stakeholders including Kelly Waples and Chris Simpson, who attended our workshops. Russ Babcock and Bill de la Mare (CSIRO) provide much needed advice throughout the project. We also thank Norm Hall, Lyndsay Joll and Brett Molony for their helpful comments on earlier drafts. Wendy Steele (CSIRO) is thanked for her efficient project management.

Data Resources
Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

The fisheries data used in the model are subject to Deed of Confidentiality and Non-Disclosure signed by CSIRO for DoFWA's data, which stipulates that written approval is required before DoFWA's data [data and data derived from the data collected by DoFWA] is published.

The model, source code, input data and data derived from the simulation model for this project are stored at CSIRO.

Knowledge Transfer
This study is a Prediction project that provides useful information on the evaluation of management strategies relevant to the conservation of target fish species (i.e. spangled emperor) in NMP. As such the findings should be useful to marine park planners and managers responsible for assessing, reviewing and amending the regulatory framework for NMP as it relates to fish conservation. Similarly, this information would be of interest to DoF for fish stock management.

6.17 Project 3.4.1: Reef morphology and growth history

Project Leader
Lindsay B. Collins (Curtin University of Technology)

Research Team
Emily J. Twiggs (Curtin University of Technology)

Project Overview
Little research has been done on the morphology and growth history of Ningaloo Reef to date, but it is considered that an understanding of underlying geomorphological factors will have a direct bearing on the nature and distribution of substrates and fauna communities, both within the reef system and on the adjacent shelf. Further, evaluating the history of reef growth and morphology through the fossil record will provide insight into the nature and rate of past environmental change over long-term timescales.

Preliminary growth history studies have revealed two stages of reef growth; a “Tantabiddi phase” during which a large fringing reef grew in an active stage of Leeuwin Current flow (ca. 125 ka U/Th ago, 1 ka = 1000 years), and a “Holocene phase” during which today’s reef recolonised the earlier reef (active reef growth during the last 7 ka U/Th; Collins et al, 2003). During habitat mapping of sanctuary zones in NMP, it was recognised that much of the lagoon substrate and geomorphology is inherited from the earlier stage of reef growth (Cassata and Collins, 2008).

We examined this relationship through regional geomorphic mapping and selected shallow coring and dating in the lagoon and near the reef crest including reef growth history and reef response over evolutionary timescales, in particular during the Holocene (last 10 ka), a period of significant environmental change. This information will facilitate predictions of future reef response to sea-level change and the links to potential changes in energy flux across the lagoon and at the shoreline, which has implications for our understanding of some of the potential impacts of climate change on a coastal reef system.

Objective
The aim of this study was to characterise the morphology and growth history of the Ningaloo Reef system and to identify the evolutionary characteristics relevant to the maintenance of marine biodiversity and climate change impacts. In particular we sought to understand whether the morphological history of Ningaloo Reef and surrounding areas would provide an insight into, and predictive capacity for, potential and future climatic changes.

To achieve this objective an investigation was undertaken on the northern Ningaloo Reef on both the west and east sides of the North West Cape to determine the:
- relationship between the Last Interglacial and Holocene reefs;
- sea-level and growth history during the Holocene (last 10 ka, Figure 1);
- chronology of reef growth initiation, development and demise;
- Holocene reef development and biofacies relationships; and,
- response of the reef system to past environmental change including sea-level rise, and the likely response to future changes.

Materials and Methods
A coring program was carried out to obtain core samples from the reef flat and reef crest within the northern section of Ningaloo Reef using lightweight portable coring equipment.

This is a high energy environment exposed to waves, necessitating careful planning of timing, equipment and logistics. The three sites selected for coring were at Osprey, Bundera and Winderabandi. Comparison was made with a core transect obtained from the Department of Planning and Infrastructure of the contrasting low energy sheltered reef environment of the Exmouth Gulf. To place the development of the Ningaloo Reef into context, a comparison was made with a modified sea-level curve for the mid-west region (Figure 1).

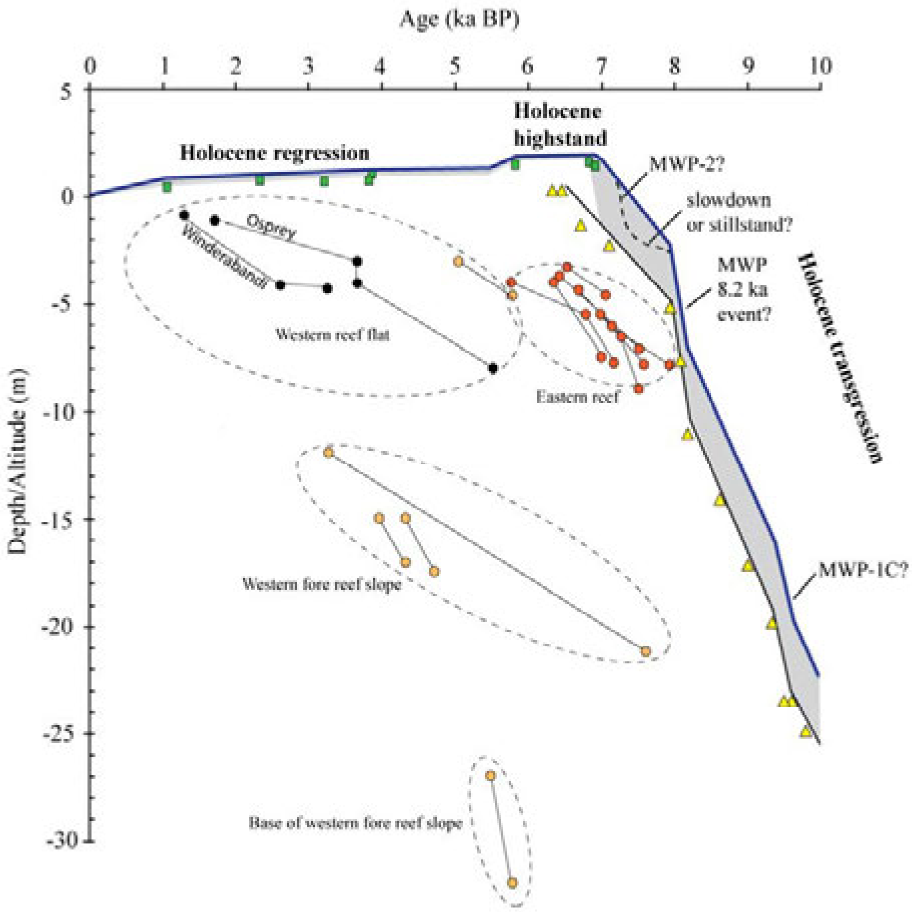

Figure 1 Compilation of Ningaloo Reef Holocene geochronology and growth history data, compared with Houtman Abrolhos data corresponding to a “catch- up” pattern of reef growth. Blue line represents interpreted sea-level curve for the WA coast. Note that reef crest data are not available for Ningaloo Reef. Data sources: Houtman Abrolhos: Collins et al., 2006; eastern reef: Twiggs and Collins, 2010; western reef; Collins et al., 2003; western reef flat: Collins and Twiggs, 2011 (WAMSI 3.4.1. Final Report).

Hyperspectral remote-sensing imagery, bathymetric data and qualitative snorkelling surveys were used to describe the contemporary reef and coastal geomorphology of both the western and eastern Ningaloo Reef, including the modern day reef communities. Additional habitat mapping of the seafloor and associated biodiversity was contributed by projects 3.4.2 and 3.1.1.

Key Findings

Overall, this study adds to previous research by providing a further insight into the Quaternary evolution of the Ningaloo Reef. The reef is built upon pre-existing topography which remains as a significant landform influence on the habitats and biodiversity. This includes widespread raised reef platforms along the coast and their eroded rock platform equivalents; canyon associated carbonate alluvial fans which form substrates for Holocene reef morphology and growth (e.g. Yardie Creek); substrates for earlier reef growth (Last Interglacial e.g. Mowbowra Creek); and ancestral karst topography.

Suitable substrate is vital for reef colonisation and subsequent growth. Core data clearly shows the phases of development of Ningaloo Reef between the Holocene (MIS 1) and Last Interglacial (MIS 5e) periods. The Holocene reef colonised the seaward margin of the last Interglacial reef, forming a build up of 10-15m below the reef crest on the west side of the North West Cape; whereas in the east it mimicked the Last Interglacial platforms and topography (Figure 2).

Reef growth is different on east and west coasts of the North West Cape, respectively. This has led to the development and growth of different communities on historic reefs. The eastern Ningaloo Reef (within the Exmouth Gulf) becomes increasingly submerged, lacking a defined reef flat. This morphology appears to be in part related to a marked change in oceanographic conditions and an increase in turbidity in the Gulf, which can affect coral community composition and ultimately carbonate accumulation. The Last Interglacial reef provided the substrate for Holocene reef initiation and further influenced reef accretion rates, reef morphology and the growth of different coral reef communities. This research has also identified that part of the eastern Ningaloo Reef was dramatically affected by environmental change during the Holocene, between 8 to 5.8 ka years ago (Figure 2). Natural processes including fluctuating sea-level, coastal flooding and erosion, increased sedimentation and turbidity, alongside severe storm activity, likely contributed to the demise of a section of the reef. Understanding the mechanisms that contribute to cessation of reef growth historically can be useful for predicting modern reef response to climate change and other anthropogenic impacts.

The history of the western Ningaloo Reef can be traced through remnant reef accreted during the Last Interglacial period. Holocene reef growth was significantly later in development than the eastern Ningaloo Reef and there has been little growth for the last 2 ka, suggesting the modern reef flat is a veneer with limited vertical reef building due to lack of space for growth to occur. This also suggests a balance of constructive (reef growth) and destructive (erosion) processes. Further, large blocks are evident at some lagoon and coastal sites as an indication of displaced reef remnants from episodic events (i.e. cyclones, tsunamis) during the Holocene.

Importantly, the timing of reef growth events has been established, together with the thickness and pattern of reef growth. We have identified the importance of reef growth characteristics and morphology for the maintenance of reef biodiversity and provide an understanding of reef conditions and environmental change over evolutional timescales. This information is timely considering the current global decline in coral reefs, and will allow marine park management to make more informed decisions on the NMP during a period of likely future change.

Finally, it should be noted that this research was of a reconnaissance nature and is by no means a comprehensive study of the whole of the reef tract, nor was it designed specifically as a climate change study. However, it has provided fundamental information on reef growth history and a potential analogue for the assessment of reef development during environmental change on coral reefs, insights that are useful for climate change assessments. For a fuller description of the project, methods and findings see Collins and Twiggs (2011).

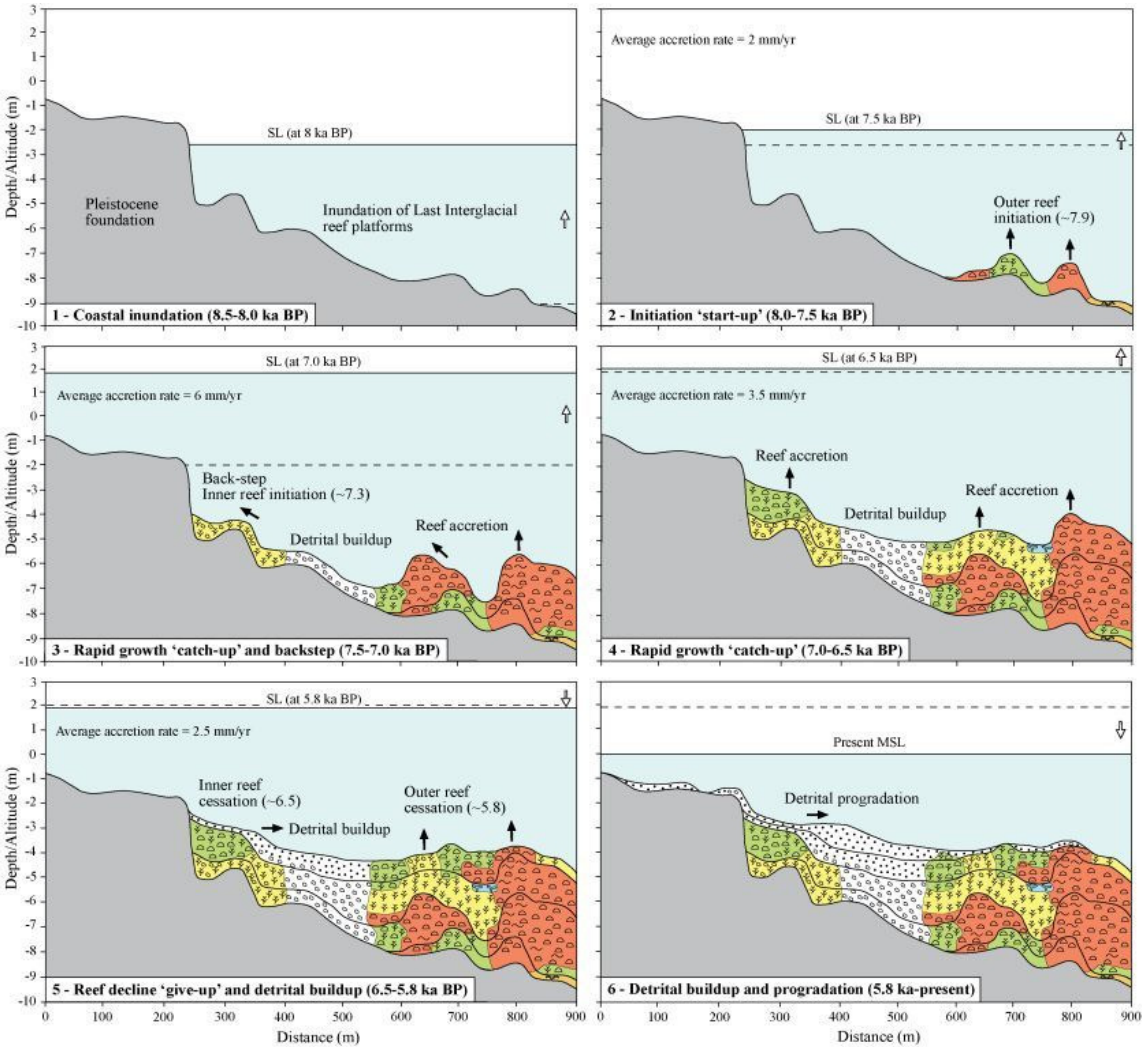

Figure 2 Chronology of reef and facies development from 8.5 ka BP to the present, Exmouth Gulf, WA. Refer Twiggs and Collins, 2010 for reef facies legend and details of isochrons (solid lines); colours or grey shades correspond to particular facies and illustrate changes during the Holocene. Solid arrows refer to the nature and direction of accretion. Sea-level data is based on the composite sea-level curve of WA (see Figure 1 and Twiggs and Collins, 2010).

Management Implications

This study has provided an insight into the effect on the growth history, geomorphic and sedimentary evolution and biological communities of sections of the eastern and western Ningaloo Reef system. This provides analogues for the assessment and prediction of future change, enabling natural resource management to adapt their management strategies of the reserves accordingly which should include promoting mitigation and supporting resilience.

Overall, the results from this study provide both baseline information and a blueprint for future research and monitoring as well as recommendations related to specific scenarios and management strategies. This information links closely to 3.4.2 and biodiversity projects within Node 3 and should be used in concert with this other information to address additional management needs and issues. Geomorphic, sedimentary and habitat information is now available in GIS map format which can provide surrogate information for broad scale biodiversity and representation of habitats for zoning assessments in the marine park. These map products can also be used to develop indicators and reference sites for long-term monitoring programs as well as in the development of coastal planning and risk assessments for climate change.

Predictions of greater intensity of rainfall events (severe storms/cyclones) and increases in sea-level during climate change will likely lead to associated increased risk of coastal erosion, storm surge and flooding (CSIRO, 2007). Thus, well planned controls need to be in place for the management of coastal development to preserve marine values and assets. This research will assist in terrestrial planning for infrastructure, providing assessments of suitable and unsuitable sites for development and/or infrastructure that need to be identified using (with other criteria) a geomorphological approach. For example, infrastructure issues that were raised after cyclone Vance in 1999 included flooding of the coastal sewage treatment facility south of Exmouth, with potential return of nutrient laden waters to the marine environment. The subsequent construction of expanded sewage treatment facilities at coastal Coral Bay also carries similar future risks especially in the case of increased event frequency/intensity.

Increasing the resilience of coral communities to adapt to change by reducing anthropogenic and natural stresses from changes to factors such as water quality and development is likely to be important wherever possible. As future land use patterns change in association with tourism development or coastal industrial activities change, the present low level of impacts from terrestrial activities to the marine environment may also change. Water quality impacts will need to be carefully managed by reducing additional local anthropogenic pressures from coastal development, or any issue that impacts on water quality/turbidity (e.g. dredging activities in Exmouth Gulf).

An understanding of potential effects of climate change from this study will enable adaptive management of the marine and terrestrial reserves accordingly, focusing efforts on mitigation and resilience. Impacts associated with predicted rises in sea-level and intensity of storm/cyclone events, including coastal wave energy, coastal sediment transport, changes in beach form and/or loss of beaches and beach amenities, flooding, changes in water quality/turbidity, burial of reef communities by sediment buildup and groundwater impacts, will need to be further understood and vulnerable sites afforded additional protection.

Impacts to the coastal environment may include erosion of the sandy coasts (e.g. Turtle nesting beaches and high value recreation areas), resulting in greater exposure of rocky shorelines which may also provide the substrate for coral reef communities to ‘back-step’ during rapid and potential ‘jumps’ in sea-level. Impacts on coral reef communities and accretion may include higher hydrodynamic energies across reef flats, through reef passes and in lagoons with greater destructive forces, which may significantly influence coral communities and reef development. The more rapid projections of future sea-level rise also may reinvigorate or ‘turn on’ reef accretion by providing new accommodation (space) into which corals may grow (Smithers et al. 2007). Identifying underlying geomorphic features that are important for reef habitats and beach development can be used to highlight vulnerable areas that may require additional protection with increasing human and natural pressures (e.g. important lagoonal habitats, effect on turtle nesting beaches etc.).

There is a very interesting story to tell regarding the geological history of the North West Cape region through periods of high and low sea-level. These factors have shaped the geomorphology of the region and are the basis for the patterns of biodiversity, including the healthy Ningaloo Reef system today. This project has produced a variety of material that could be used for interpretive display to promote a better understanding of geological history, its impact on the world around us today and changes we can expect in association with climate change impacts. Promotion of communication and awareness to local users, tourists and industry should be a developing priority as an investment tool for reducing local reef dependent tourism impacts and carbon footprints, further improving reef resilience to change.

Finally, this research sets the stage and provides background baseline information for further investigation on impacts of predicted climate and sea-level change on ecological assets for future management planning. A number of areas have been highlighted that would benefit from further research including:

- Further development of predictive models for environmental and climate change, including coastal risk and change models based on a range of predicted sea-level changes for the area, the physical domain and relevant historical changes;
- Investigation of the slowly growing reef present at Bundegi and the communities associated with large *Porites* in Exmouth Gulf.
- Establishment of a marine and terrestrial GIS of the whole system would facilitate identification of underlying features related to habitat development that can be used to highlight vulnerable areas that may require additional management with increasing human pressures.
- Additional reef growth studies to understand sea-level history specific to Ningaloo and reef response during Holocene evolution (including community structure, storm/cyclone occurrence).
- Reef growth studies to understand the organisms and processes involved in reef development (including seismic, coring and geochronological studies) and accretion studies (e.g. specific communities, erosional processes, binding organisms etc).
- Establishing accurate palaeohistories of storm occurrence and tsunamis along the coastline.

In addition to further research, this project highlights particular reef characteristics and values that should be monitored for change as a means of assessing climate change impacts and reef resilience and vulnerability, including calcification and accretion rates of corals such as *Porites,* modern coral communities, and water quality, sedimentation and turbidity.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

This research has collected data on core data, reef stratigraphy and identification of biological samples, U-series thermal ionization mass spectrometry (TIMS) dating of coral samples. It is stored in Excel spreadsheets containing core data and U-series dating information on the Curtin Science and Engineering server.

Knowledge Transfer

This project is a baseline investigation of the physical background to NMP. It has provided foundational information useful in future planning for research, monitoring and management activities. This information should be of interest to planners developing the coastal environment as well as natural resource management.

6.18 Project 3.4.2: Characterisation of Geomorphology and Sedimentology

Project Leader
Professor Lindsay B Collins (Curtin University of Technology)

Project Team
Emily Twiggs, Sira Tecchiato (Curtin University of Technology)

Project Overview

The representative protection of marine biodiversity relies on an understanding of the ecosystem components that define benthic habitats (Post et al., 2006; Verfaillie et al., 2009). Seafloor habitats include the physical abiotic aspects of the seabed environment such as geomorphology, sediment composition (texture, mineralogy and constituents), mobility of the substrate, bathymetry, rugosity, the hardness and roughness texture of the seabed and water depth (Brown and Collier, 2008; McArthur et al., 2010). These physical factors can be significant in describing the distribution of benthic biota and fish distributions over broad geographic regions (Williams and Bax, 2001; Roff et al., 2003; Beaman et al., 2005; Ball et al,. 2006; Post et al., 2006; Verfaillie et al., 2006; Wedding et al., 2008; McArthur et al., 2010; Twiggs et al., 2011). Physical parameters can also be measured much more quickly and across wider areas than biological information, providing rapid assessments for the selection and ongoing monitoring of MPA's (Post et al., 2006; Verfaillie et al., 2009).

NMP provides an ideal case study to advance baseline understanding of near pristine reef geomorphology, sediment distribution and habitat variability, and establish the current condition of the reef for the evaluation and monitoring of future change. During initial habitat mapping of sanctuary zones in NMP (Cassata and Collins, 2008) it was recognised that much of the lagoon substrate and geomorphology, important for shaping modern coral reef habitats, is inherited from an earlier "Tantabiddi" stage of reef growth during the Last Interglacial (ca. 125 ka ago, 1 ka=1000 yrs) (Collins et al., 2003; Collins, 2011b). Diverse filter-feeding communities on the adjacent shelf, are also strongly influenced by antecedent shelf topography and substrates (Cassata and Collins, 2008; Twiggs et al., 2011). An understanding of seabed geomorphology and bedform environments will have a direct bearing on the nature and distribution of substrates and communities, both within the Ningaloo Reef system and on the adjacent shelf.

Objective

The overall aim of this project was to determine the geomorphological and sedimentary characteristics (biological and physical) of the Ningaloo Reef and shelf, and to identify evolutionary characteristics relevant to the maintenance of marine biodiversity. This included characterising reef growth history, coastal and seabed geomorphology, surficial sediment facies and their influence on the distribution of benthic habitats. This research presents an interdisciplinary study that provides an important baseline for future habitat mapping, biodiversity assessments, spatial planning, and fisheries management. The characterisation and mapping of benthic habitats based on physical parameters is central for the ongoing monitoring, management and conservation of the NMP's inshore and offshore resources, particularly during a time of increasing anthropogenic and environmental pressures.

Materials and Methods

To achieve these objectives broadscale investigations were undertaken for the entire NMP and in detail for the northern Ningaloo Reef and shelf, to map and characterise bathymetry and seabed texture, geomorphology (reef and shelf zones/features), sedimentary bedform environments, surficial sediments (physical and biological components) and associated benthic communities. Both the inshore and offshore components of this research present an interdisciplinary study through the use of reef coring and dating, remote sensing mapping techniques, GIS modelling and interpretation, and ground-truthing data.

The shallow inshore coral reef environment of the northern NMP was assessed through finescale surveys of habitats, coral community structure, surficial sediments, geomorphology and reef fish assemblages (a collaborative effort with Project 3.2.2f). This study expanded on the earlier mapping by Cassata and Collins (2008) to investigate contemporary reef and coastal geomorphology using hyperspectral remote sensing imagery draped over 3D bathymetric models, to further characterise reef structure and geomorphic zonation. Diver-operated benthic video was used to survey specific lagoon habitats and these were supported by digital photo-quadrats to measure coral community structure and variability within major habitats.

The offshore component of the project (seawards of the Ningaloo reef slope) focused on mapping the seafloor with acoustics (multibeam and single beam) and collecting towed-video data, sediment grabs and dredged samples to verify acoustic interpretations, and characterise the geomorphic, sedimentary and biological aspects of the seabed. Finescale investigations were undertaken in a section of the northern shelf to develop a robust methodology by which multibeam data could be transformed into classified map products. Classified maps were then draped over 3D bathymetric models to further characterise geomorphic and bedform environments, and their associated communities.

Surficial sediment samples were collected spanning the entire inshore and offshore NMP using a widely spaced systematic grid of samples to provide broadscale map coverage. All sediment samples were analysed for grainsize statistics, textural parameters and descriptive terminology (such as fine gravelly sand) using standard classification schemes. Component analysis was undertaken on representative samples to examine the contribution of carbonate producing organisms to the sediments. The offshore component was run in collaboration with project 3.1.1.

Further details on methodology can be found in Cassata and Collins (2008) and Twiggs et al. (2011).

Key Findings

This research was reconnaissance in nature and is by no means a comprehensive study of the whole of the reef tract and continental shelf, but it has provided fundamental information on ancestral and contemporary geomorphology and sedimentology of the NMP, the oceanographic processes that have contributed to the formation of sedimentary bedforms and the influence of physical environments on benthic communities. These relationships may be used to inform our understanding of benthic habitat variability across the NMP, and aid in the development of habitat maps central to the ongoing conservation and monitoring of biodiversity at NMP.

Ancestral Controls

The Last Interglacial fossil reefs of Ningaloo, strongly controlled Holocene reef development over the last 8 ka and the modern geomorphology and community zonation that we see today. The high energy western reef has been influenced by fluctuating sea-level during the Holocene, with the formation of relict ‘’give-up” reefs and multiple backstepping spur and groove systems on the fore reef slope, formed as the reef tried to "catch-up" to sea-level. The modern reef flat has grown to sea-level and is currently a veneer of corals with little vertical growth, due to the balance of destructive and constructive processes acting on the reef. There is the likelihood however, that the reef is currently prograding (growing seawards) at the reef crest. Pleistocene alluvial fans that were deposited from ephemeral creeks and gorges during lower sea-levels, also provide the substrate for modern reef growth. Extensive channels and gutters in the reef and lagoon suggest an element of karst control on reef morphology.

In contrast, a section of the eastern reef typifies a ''give up'' reef, that ceased to grow 5.8 ka ago due to a combination of environmental changes including fluctuating sea-level, coastal erosion and flooding, increased sedimentation, and storm/cyclone activity (refer to Twiggs and Collins, 2010 and Collins and Twiggs, 2011). Reef structures such as drowned terraces and spur and grooves in the fore reef zone, relict alluvial fans forming reef flats, and channels and gutters in the back reef, provide important habitat for a variety of contemporary coral reef communities.

Major storm events and tsunami have also impacted the Ningaloo coastal zone during the Holocene, with erosion of coastal dunes and pavements, and the deposition of reef material (1 km inland) related to major storm/tsunami washover events.

Contemporary Reef Geomorphology and Zonation

The western Ningaloo Reef generally displays distinct geomorphic zonation (Figure 1) with strong correlation between morphology, inherited substrate type, and habitats from the reef front to the shoreline (Figure 2). Five geomorphic reef zones and associated features, include the following:

- Fore reef slope - mid-upper slope spur and groove systems, lower slope ridges, pinnacles and mounds, sandy linear depressions;
- Reef crest - coralline algal reef rim, oyster-encrusted raised pavement/blocks;
- Reef flat - inner, mid and outer flats, reef gutters and holes;
- Back reef lagoon - subtidal/intertidal limestone pavements, sand flats, patch reefs, coral gardens, lagoon channels/moats, lagoon ridges, sand aprons;
- Reef passes.

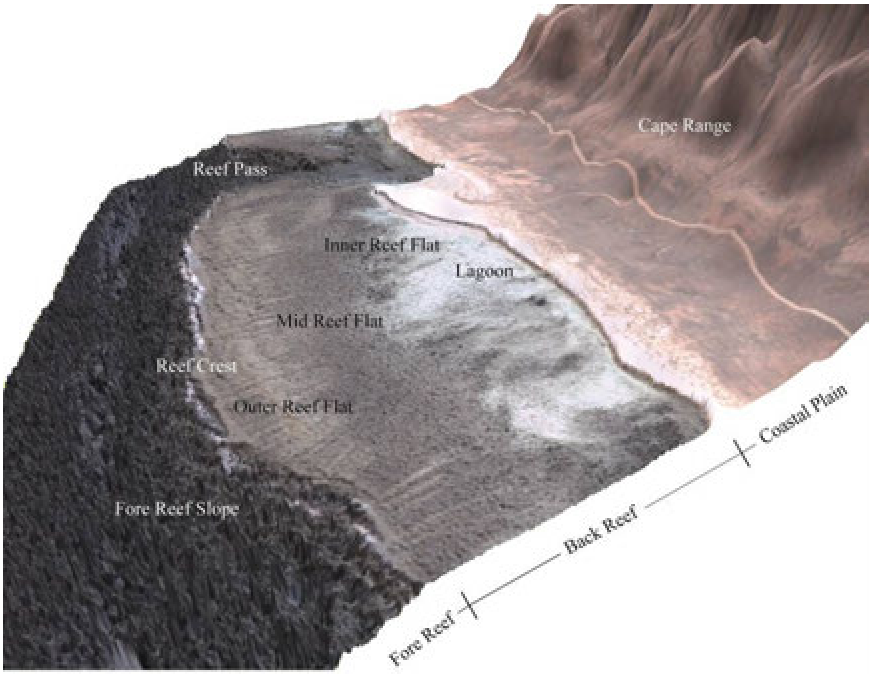

Figure 1. Geomorphic zones of the Ningaloo Reef, Turquoise Bay, Mandu sanctuary zone.

For a detailed overview of coral reef environments and structures refer to Collins and Twiggs (2011).

The eastern Ningaloo Reef within the Exmouth Gulf, becomes increasingly incipient and is best described as a submerged reef that lacks a defined reef flat. This morphology appears to be in part related to a marked change in oceanographic conditions and an increase in turbidity in the Gulf, which can affect coral community composition and ultimately carbonate accumulation (Collins and Twiggs, 2011; Twiggs and Collins, 2010).

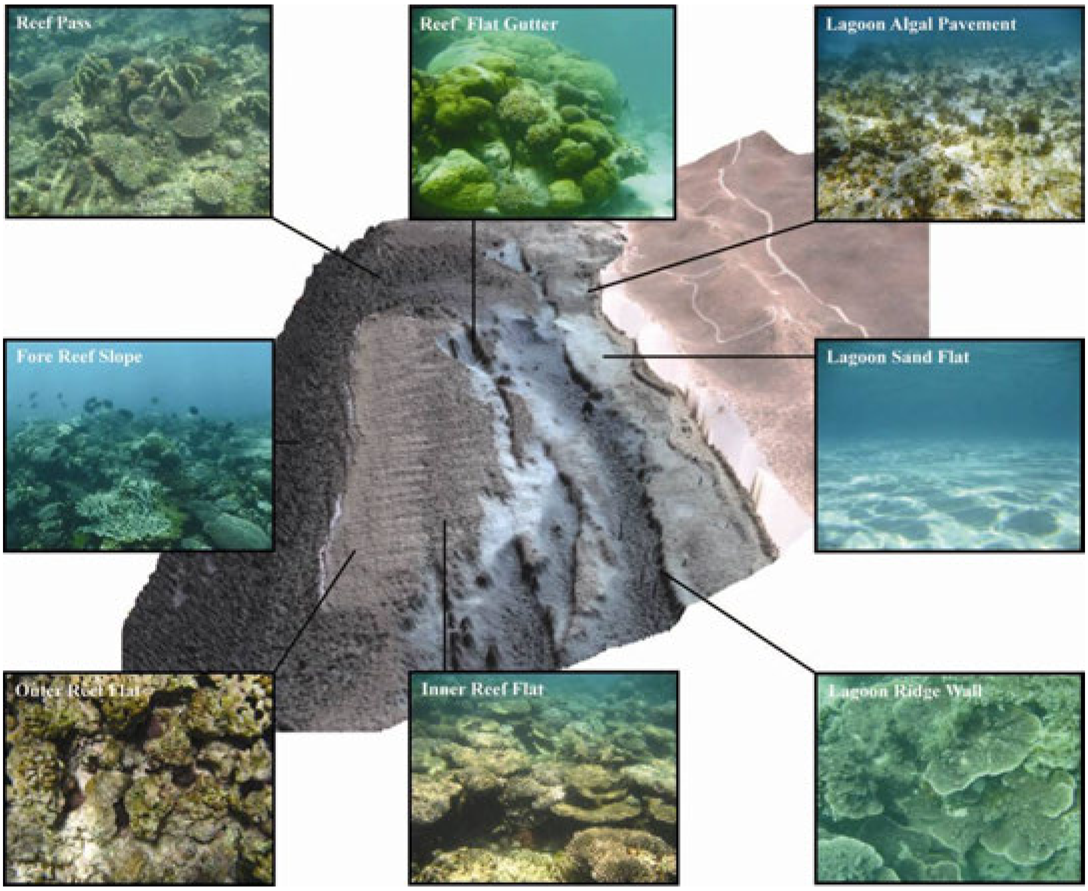

Figure 2 Summary of coral reef habitats of the northern Ningaloo Reef, Osprey sanctuary zone.

Coral Reef Assemblages

A total of 40 coral genera and 100 species were identified during habitat transect surveys of the northern NMP. *Acropora* dominates the reef flat and shallow fore reef slope habitats, with other common genera including *Montipora*, *Porites*, *Seriatopora* and *Favites*. While it can be difficult to delineate reef zones based on coral species composition, Cassata and Collins (2008) found that there was a transition of more robust to delicate forms of coral landward of the reef crest. Seven morphological coral assemblages (robust-branching, tabular-branching, arborescent, domal, foliaceous, encrusting, and mixed), with associated species and other benthos, have been classified across the geomorphic zones and features of NMP (refer to Twiggs et al., 2011). In addition, a common carbonate producing assemblage includes the coralline-algal assemblage which forms crusts on the reef framework.

Continental Shelf Geomorphology, Sedimentary Environments and Habitats

The extensive Ningaloo Reef system lies adjacent to a gently sloping and distally-steepened carbonate shelf. There is a distinct latitudinal variation in shelf width and bathymetry. In the northern sector between Osprey to Mandu, the shelf is narrow at ~7.5 km (from coastline to shelf break) with a marked change in gradient at the shelf break in 125-145 m, reaching depths of 110 m within NMP. The central sector at Point Cloates marks a transition in bathymetry where the shelf widens to ~25 km, and at Red Bluff in the southern end the shelf extends to ~50 km offshore, reaching to depths of only 50 m within NMP. Distinct geomorphic zones in the northern NMP include the inner, middle and outer shelf, and shelf break and slope canyon heads at the seaward margin. Shelf zones classified based on bathymetry, seabed texture and distinct geomorphic features, include contemporary reefs, platforms and ridges (relict reefs and/or shorelines), sedimentary bedforms, extensive sand flats and submarine fans. Refer to Twiggs et al. (2011) for a detailed overview.

There is a strong association between geomorphology and benthic habitats (Figure 3) with hotspots of highly biodiverse, filter feeding habitats (particularly sponges) correlating with hard limestone substrates and gravelly sediments. The thickness of shelf sediments has not been determined, but the formation of barchan dunes and the frequent exposure of the underlying limestone substrate indicates a shallow veneer of sediments across most of the shelf. Filter feeders also emerge from coarse sandy habitats which also suggests this is the case. At the base of the highly rugose Ningaloo fore reef slope (35-40 mwd), hard corals rapidly disappear and are replaced by mixed deeper-water, filter feeding communities on inner shelf pavements and extensive gravel/rubble beds (most commonly rhodoliths) with varying mixes of sand. Extensive and largely uncolonised flat and rippled sandy habitats dominate the mid to outer shelf, interspersed with coarse biogenic gravel fields and low relief ridges/pavements, providing habitat for exotic sponge, gorgonian and bryozoan 'gardens'. The density of filter feeders is particularly high on limestone ridges adjacent to continental slope canyons, which bring nutrient rich, cold-water upwelling to the shelf edge. On the outer shelf, below fair-weather wave-base, bioturbation is evident from echinoderm feeding traces, polychaetes and burrowing fish, and a diverse infauna has reworked finer sediments to build mounds and burrows. Fields of large gravel mounds and pits (~95 mwd), may indicate conduits to coastal groundwater and paleo-channel sites (refer to Collins and Stevens 2010; Collins and Stevens this volume).

A more complex history exists in the Point Cloates region, where paleo-stillstand escarpments and shorelines, and very high relief stepwise fossil reefs and pinnacles support diverse coral, algal and sponge-dominated communities. Rhodolith beds are common in the central sector of NMP and rippled sandy habitats dominate to the south. An offshore ridge and pinnacle system, and exposed pavement at the southern end of NMP, between Gnaraloo and Red Bluff, provide the hard substrate for highly diverse and dense, sponge-dominated filter feeding communities (project 3.1.1a and d).

Shelf Dynamics

Identification of sedimentary bedforms has enabled the characterisation of sediment transport pathways and oceanographic currents acting on the northern Ningaloo shelf. Complex dune fields on the inner to mid shelf indicate the presence of currents that originate down the reef slope and flow onto the shelf. Large submarine fans and associated dunes form from the flushing of lagoon waters through reef passes onto the inner shelf. A zone of interaction (~45-65 mwd) occurs between inner shelf processes and the wind-driven northeast flowing Ningaloo Current, which dominates the mid shelf forming linear ribbon dunes and scours. An additional zone of interaction occurs on the outer shelf (~75-95 mwd), between the Ningaloo Current and the oceanic Leeuwin Current which intrudes onto the edge of the shelf, and is responsible for the formation of 'very large' southwest migrating dunes. Large hummocky dunes, formed between fair-weather wave-base and storm wave-base, create an undulating surface on the outer shelf.

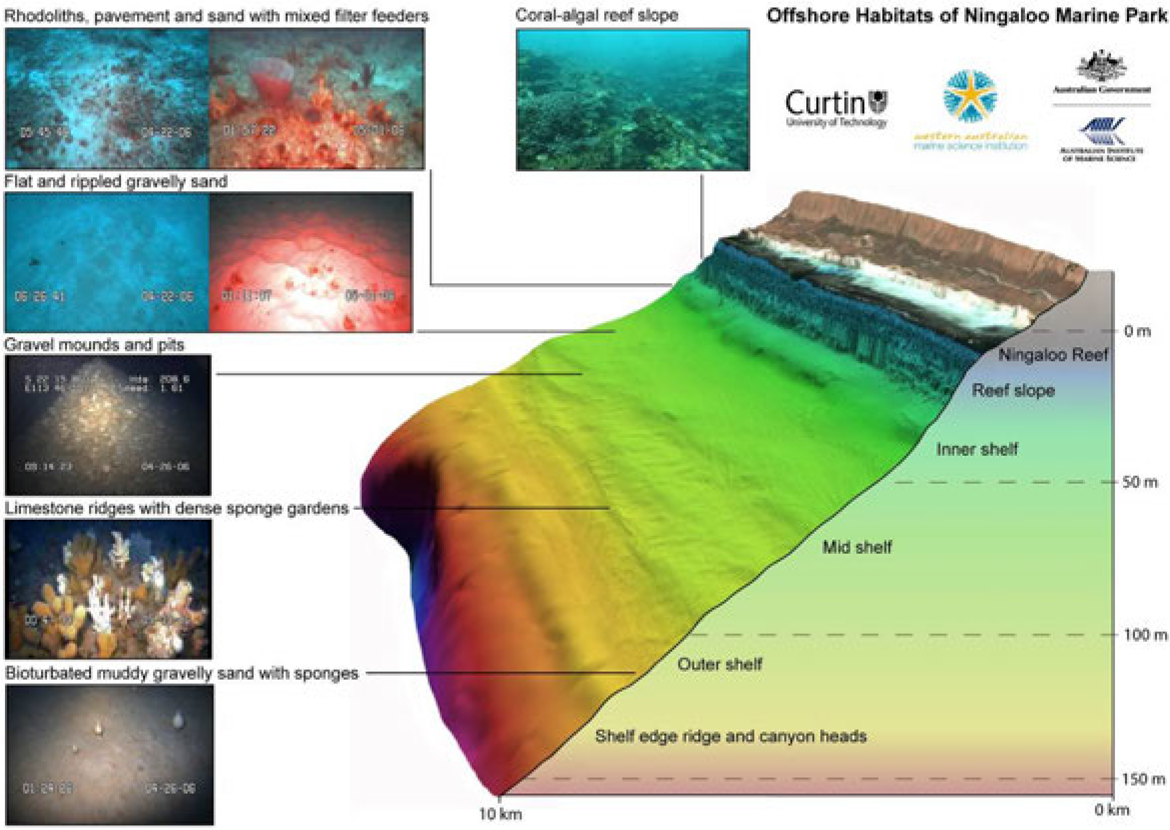

Figure 3 Geomorphology and summary of cross-shelf habitats of the northern Ningaloo shelf, Mandu.

Mapping Seabed Sediments

Interpolated sediment grain size distribution has been mapped for the entire NMP (Figure 4). Sediments are generally poorly sorted and high in calcium carbonate ($CaCO_3$) content (82% average). Surface sediments in the central and northern sectors are predominantly gravel to sand mixes, with gravel increasing in the vicinity of hard substrates. Mud content increases on the outer shelf, particularly adjacent to continental slope canyons. Rippled sand dominates the southern sector of the NMP. Textural analysis of sediments has also identified sub-parallel belts across the narrow, northern shelf, and the strong linear relationship between mean grain size and multibeam backscatter intensity provides a complete seafloor coverage map of predicted mean grain size. In addition, classified substrate maps using video observations are extremely useful when describing the composition of geomorphic and sedimentary features and their associated benthic communities.

Sediment Components

NMP lies in a latitudinal transition zone of carbonate producing communities where both photozoan-reef (warm-water/low nutrient) and heterozoan-carbonate shelf (cool-water/elevated nutrient) producers are found. The study of this unique, near-pristine system provides one of the best analogues for predicting the response of shallow-water carbonates under environmental change. Surface sediments are predominantly biogenic grains and palimpsest, preserving a record of older grains mixed with modern Holocene material. The sediments have assumed the character of the benthos, becoming a proxy for the modern and fossil communities that produced them.

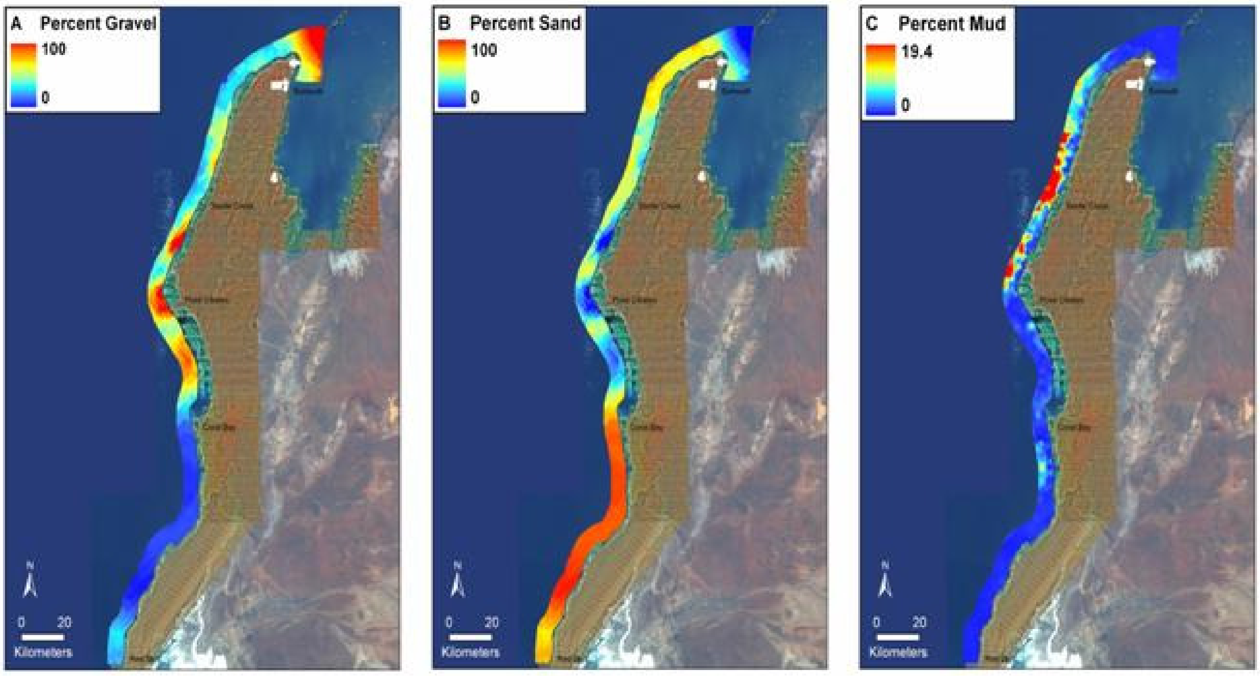

Figure 4(a-c) Sediment grain size (% gravel, sand and mud) for the NMP.

Management Implications

This study has provided an understanding of the geomorphic and sedimentary evolution, and associated biological communities. Geological and sedimentological data have been consolidated into a Geographic Information System (GIS) to aid in the production of geomorphic, sedimentary facies and benthic habitat maps of the Ningaloo Reef and adjacent continental shelf within the NMP. This research has established a baseline understanding of the geomorphology and sediment distribution in the shallow inshore and deeper offshore waters of the NMP, with an understanding of their influence on the spatial distribution of benthic habitats and communities. The characterisations determined at this scale improve our understanding of benthic habitat variability across the NMP and provide a baseline for additional habitat studies.

This research provides management with the basis for future planning and zoning assessments based on geomorphic features that support specific benthic community and fish assemblages requiring protection. For example shelf features including ridges, rhodolith beds and gravelly sediments have been identified as important sites for highly biodiverse filter feeding communities. Areas not currently represented in the NMP sanctuary zones, including shelf edge ridges which contain very high biodiversity, should be considered for further protection. Identifying physical and biological surrogates for many benthic marine organisms is essential for the future of habitat mapping and improving the accuracy of predicting marine biodiversity (Heap and Harris, 2011).

Reef geomorphology and shelf features such as extensive ridge systems, document sea-level history and growth/erosion on the shelf which can provide an important analogue for climate change assessments (refer also to WAMSI Project 3.4.1). This research has also identified sites along the Ningaloo Reef tract and along the coastal dune system that have been subject to high intensity storm/tsunami events. With predictions of greater intensity of severe storms/cyclones and the associated increased risk of coastal erosion, storm surge and flooding (CSIRO, 2007), stringent controls need to be in place for the management of coastal development and tourism nodes. This research will assist in terrestrial planning for infrastructure, providing assessments of suitable and unsuitable sites for development and/or infrastructure that need to be identified using (with other criteria) a geomorphological approach. The potential interactivity between terrestrial environments (including natural systems and infrastructure-related changes) and the nearshore marine systems will need careful consideration. Recommendations for future management would include supporting further investigations of the paleohistories of major storm occurrence and tsunami impacts along the coastline, to identify sites of elevated vulnerability to these events.

Full coverage GIS-based maps produced during this research are essential for baseline and monitoring phases for marine conservation, fisheries management and are important for planning future management activities including protecting key biodiversity. The mapping of physical environments (geomorphology, sediments and seabed texture) into a GIS system has facilitated the identification of underlying geomorphic features and sedimentary environments, important for habitats and beach development, that can be used to highlight vulnerable areas requiring additional protection with increasing human pressures (e.g. important back reef habitats, effect on turtle nesting beaches). Increasing the resilience of communities to adapt to change by reducing anthropogenic and natural stresses, from changes to factors such as water quality and development, is likely to be important wherever possible. As future land use patterns change in association with tourism development or coastal industrial activities change, the present low level of impacts from terrestrial activities to the marine environment may also change.

Future Research

Within the constraints of a limited budget significant findings have been made on the geomorphology, sedimentology and habitats of the Ningaloo reef system and adjacent shelf providing a baseline for future research and reference sites for long-term monitoring. However, much geoscientific work remains to be done before our knowledge of the Ningaloo system can be compared with, for example, the information assembled for the Great Barrier Reef. Future research to address knowledge gaps could include the following:

- Analysis of existing data collected as part of this project that was out of the current scope and budget including:
  - Detailed characterisation and mapping of biological assemblages within carbonate sediments, which will provide a baseline prior to predicted impacts on carbonate secreting species, in response to environmental change.
  - Dating of grains to determine the evolution of assemblages during past environmental change.
- Investigate the use of geophysical surrogates for predictive mapping of marine biodiversity that can be used for marine planning, monitoring and general conservation (with project 3.1.1).
- Investigate the links between geomorphic features identified on the shelf (gravel mounds and pits) and the coastal groundwater system.
- Dredging and coring projects to establish the formation of offshore features such as relict reefs and ridges that are currently important habitats for diverse filter feeding communities.
- Understanding and ongoing monitoring of sediment budgets of the Ningaloo Reef system and shelf and links to landforms and processes. This is particularly important to understand due to the dynamic nature of sedimentary environments and the influence on biological communities.
- The significance of spatial variations in geomorphological sensitivity and vulnerability to the effective management of critical organisms and habitats.

- Further understanding of the timing of major storm/tsunami events along the Pilbara coastline.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

GIS referenced map layers of bathymetry, sediment statistics, substrates and geomorphology have been produced and are stored on the Curtin Science and Engineering server.

Knowledge Transfer

This project is an inventory of the geomorphic and sediment features of NMP. It has produced map layers which will be a valuable tool to a range of roles within DEC including marine park planning, operational management, research and monitoring. This information should also be of use to other government agencies and industry that have an interest in the Ningaloo coastal region.

6.19 Project 3.5.1: Hydrodynamic Processes of Fringing Reef Systems: Ningaloo Reef, Western Australia

Principle Investigator
Charitha Pattiaratchi (University Of Western Australia)

Research Team
Soheila Taebi, Ryan Lowe, Greg Ivey (University of Western Australia), Graham Symonds (CSIRO Marine and Atmospheric Research)

Project Overview
Water motion is known to control a number of key ecological and biogeochemical processes on coral reefs. In general, the circulation within coral reef systems can be driven by a number of forcing mechanisms, including surface wave breaking, tides, wind and buoyancy effects (Monismith 2007). The relative importance of each of these mechanisms depends not only on the external forcing climate present at a given site, but may also depend strongly on the particular morphology of the reef itself (Lowe et al. 2009). For wave exposed reefs, many studies have observed that reef circulation is dominated by the effects of depth-limited wave breaking (e.g., Monismith 2007). The dynamics of these wave-driven reef flows thus have some broad similarities to the currents generated by waves in other nearshore systems, such as on beaches (e.g., MacMahan et al. 2006). On reefs, wave breaking on the reef slope (forereef) generates cross-shore gradients in the radiation stress (i.e., the excess momentum due to the presence of the waves) (Longuet-Higgins and Stewart 1964). Over the reef flat, the cross-shore gradients in radiation stress effectively vanish once wave dissipation ceases outside the surf zone, but continuity requires a current to match the cross-shore volume flux through the surf zone. This causes a pressure gradient to develop across the reef flat with an increase in sea level (wave setup) at the top of the reef slope, which in turn produces a pressure gradient through the surf zone opposing the flow. Therefore, on a reef the cross-reef gradient in radiation stress through the surf zone is partitioned between driving a cross-reef current and supporting a pressure gradient. In the two-dimensional case, the cross-reef volume flux must flow alongshore in the lagoon towards any channels in the reef. This alongshore flow must also be forced by an alongshore pressure gradient, causing the lagoon sea level to increase in the lagoon and decrease towards the channel. The increase in lagoon sea level must in turn decrease the cross-reef pressure gradient and the corresponding cross-reef flow.

To date, most of the experimental and theoretical studies of wave-driven circulation in coral reefs have primarily focused on ‘barrier reefs’ or ‘atolls’. Conversely, relatively few field studies have been conducted to investigate the dynamics of wave-driven flows generated within fringing reef systems such as Ningaloo Reef, which, occur adjacent to a coastline, and thus have relatively shallow lagoons that are only free to exchange with the ocean through narrow gaps (channels) in the reef. As a consequence, existing analytical models of reef circulation developed specifically for barrier reefs and atolls may not be directly relevant to predicting the circulation and flushing of fringing reef systems.

Objective
The objective of the present study is to examine the detailed dynamics of wave-driven flows within Australia’s largest fringing coral reef system, Ningaloo Reef. The nearshore circulation of this reef was investigated from an intensive field study described in Taebi et al. (2011c). The field study focused specifically on the dynamics governing circulation in a ~5 km section of Ningaloo Reef centred at Sandy Bay (Figure 1). This site was chosen because the reef appeared, from aerial photographs, to have morphological

characteristics fairly representative of NMP as a whole, with the measurement program focusing on a single channel with reef sections on either side. As shown below, the study area represents an individual reef-channel circulation cell; thus, when considered as a whole, the circulation of the entire 290 km Ningaloo Reef tract can be thought of as being comprised of many of these functionally similar reef-channel circulation cells.

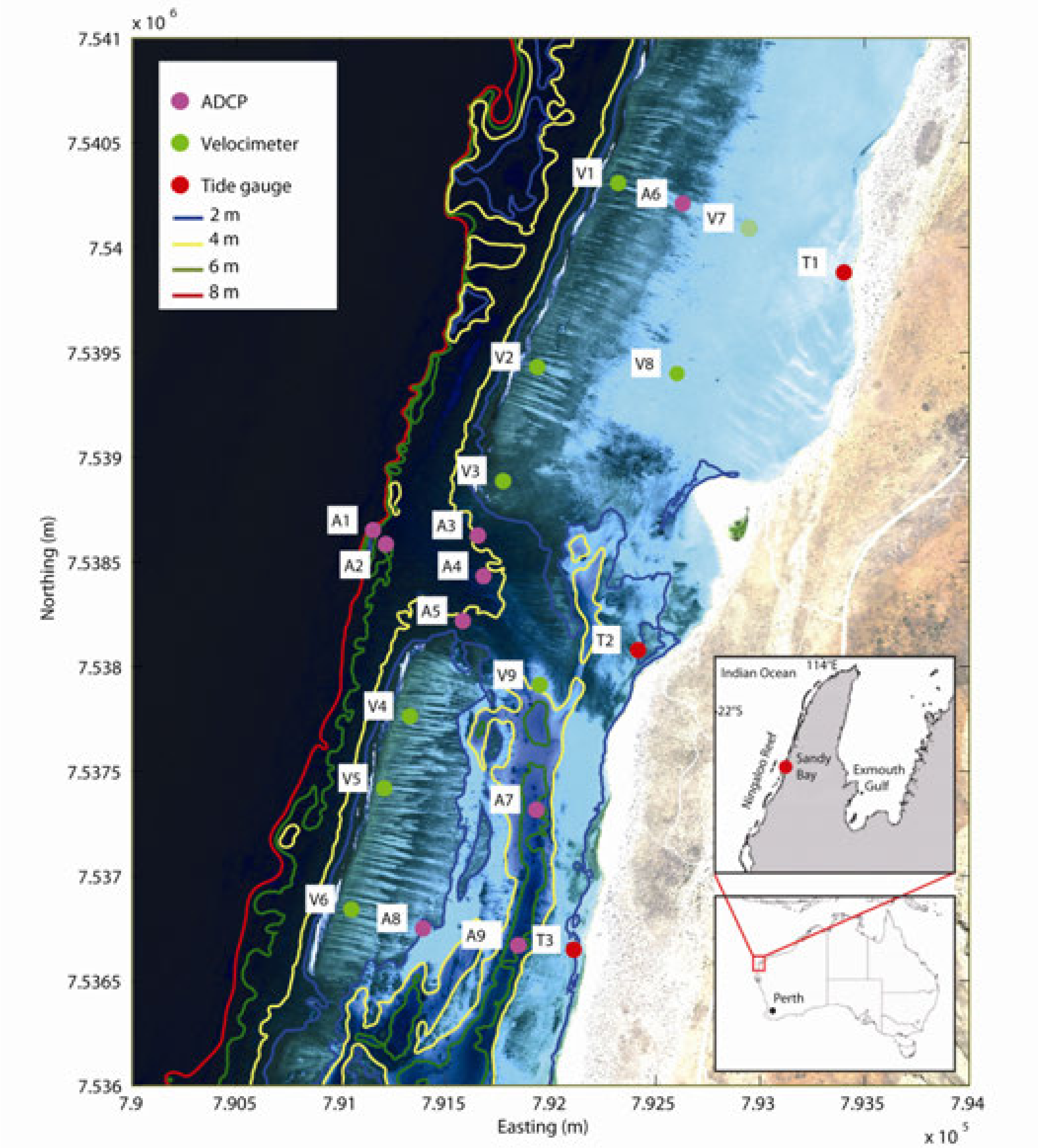

Figure 1 Map of the study area at Sandy Bay in NMP. Isobaths between 2 m to 8 m are superimposed to highlight the key features of the reef morphology. The locations of the moored instruments during the field experiment are also shown. The white bands visible along the reef crest show wave breaking, highlighting the narrow surf zone.

During this study, the flows were found to be dominantly wave-driven, yet still much weaker than many other reefs experiencing comparable wave conditions. This was attributed to the role of significant friction in the relatively shallow lagoon, supported by observations of substantial wave setup (comparable to the maximum over the reef) within the lagoon. The modelling part was built on the work of Taebi et al. (2011b) to first develop and test a new coupled wave version of the Regional Ocean Modelling System (ROMS) (Warner et al. 2008) to accurately predict the wave-driven flows within NMP's complex reef morphology. The model was then used to examine the detailed dynamics of the wave-driven flows, by examining the dominant momentum balances established locally in various regions of the reef lagoon system (Taebi et al. 2011a). The field study was conducted specifically in the austral autumn when wave heights and wind speeds in the region were seasonally at their minimum, so a second aim of the modelling work was to investigate the importance of wave forcing to Ningaloo's circulation, in the annual cycle. The model was thus extended to different periods of time, to investigate the relative importance of wave and wind forcing over a seasonal cycle.

Methodology

An intensive 6-week field experiment was conducted during April and May 2006 when 21 moored instruments were deployed at sites spanning from the fore-reef slope to the lagoon (Figure 1). We measured current profiles on the forereef, channel and reef flat as well as hourly directional wave spectrum. We also sampled pressure and current velocities at a fixed height typically near the middle of the water column. Tide gauges were deployed in the lagoon adjacent to the shore, and sampled water level from recorded pressure. A series of thermistor-chains were also deployed in the lagoon adjacent to the channel, to investigate vertical density stratification in the deeper regions (note that the system receives effectively no freshwater discharge from its arid coastline). Analysis of the thermistor records revealed the lagoon was well-mixed throughout the experiment (not shown), so buoyancy effects were not considered in any subsequent analysis.

The numerical modelling was based the Regional Ocean Modeling System (ROMS). In particular, coupled wave-circulation modelling was conducted using the wave-current interaction routines implemented into the source code by Warner et al. 2008. The transformation of random, short-crested surface waves was simulated using the SWAN wave model (Booij et al. 1999).

Field measurements were collected in the autumn period, however the model was applied to additional summer and winter periods taking into account seasonal variability in wave and wind forcing.

A variety of derived hydrodynamic parameters can be defined to estimate the rate at which a coastal system, such as Ningaloo Reef, exchanges water with the ocean. The seasonal variability in the flushing time (T_f) for this section of Ningaloo Reef was investigated in a series of simulations. For fuller details on methodology, models and analysis see Taebi et al 2011, Taebi 2011.

Key Findings

The time series of the current speed U over the reef flat showed stronger subtidal current variations with a superposition of weaker tidal fluctuations. The total current variability primarily resulted from changes in the incident wave energy, with correlation coefficients between the incident wave heights and current speeds ranging from R~0.5-0.9 for all sites on the reef flat, and R~0.8 for the channel flow (Figure 2). There was no significant correlation between the wind stress and current speeds observed at all sites (R~0.1). While the currents increased in a monotonic fashion with increasing wave height, a more complex relationship is apparent between the currents and tidal variations. The correlation between the tidal elevation and current speed was relatively weak (R<0.3) at all sites, however, for the shallower reef sites (V1 and V6) a nonlinear (quadratic) response is clearly visible, which can partially explain the low linear correlation values (Figure 2d, f). This nonlinear response is most evident at the southern reef site (V6), where at high tides (+0.5 elevation) the flow is virtually absent, then increases as the tidal level is reduced, and then the flow again became negligible at lower tides (< -0.4 m). At these low tides, visual observations in the field indicate that the reef crest may become exposed in some parts (but not continuously along the reef crest), which would significantly limit any cross-reef flow. Thus for this site (V6) and to some degree at the northern site (V1), reef current speeds were at a maximum at some intermediate depth between high and low tide, i.e. an optimum appears to occur when the tide is 0.2-0.4 m below the mean water level.

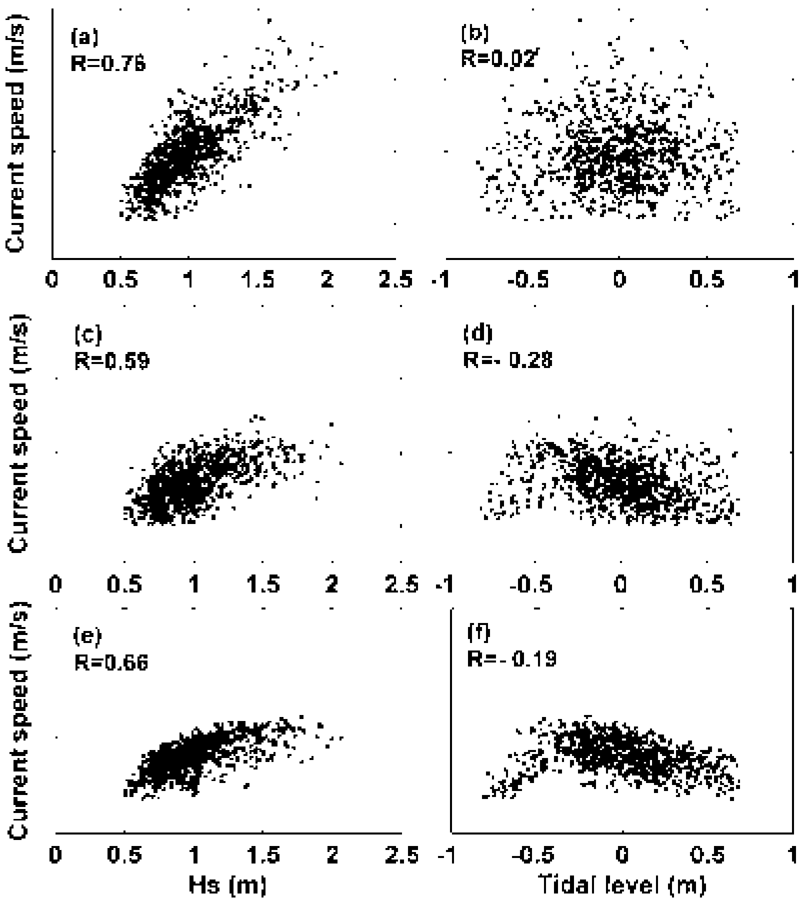

Figure 2 The response of the current speed (non-filtered) to key forcing mechanisms (wave and tide), observed in the channel A4 (a, b), northern reef flat V1 (c, d) and southern reef flat V6 (e, f).

SWAN wave model outputs, evaluated for the range of γ and k_n, were compared to the observed wave heights at the five sites. These simulations revealed that the best overall model skill occurred when γ=0.5 and k_n=0.5 m, producing a site-averaged skill value of ~0.7.

$$Skill = 1 - \frac{\sum \left| X_{model} - X_{obs} \right|^2}{\sum \left(\left| X_{model} - \overline{X}_{obs} \right| + \left| X_{obs} - \overline{X}_{obs} \right| \right)^2} \quad (2)$$

$$RMSE = \sqrt{\overline{(X_{model} - X_{obs})^2}} \quad (3)$$

The skill for the reef flat sites was typically 0.6-0.7. The RMSE for all sites were typically 0.1-0.2 m with a typical bias of +0.1-0.2 m, indicating the model was slightly over predicting the wave height on the reef flat.

The performance of the circulation model was investigated as function of varying bottom roughness z_0, with the currents speeds best predicted for all sites using z_0=0.03 m. RMSE values were <0.1 m s^{-1} for all sites (averaging ~0.05 m s^{-1}) and there was no consistent bias across the sites. The time-averaged current vectors over the two-week hindcast period generally agree very well with the field observations, with a cross-reef flow towards shore on reef flat, alongshore flow in the lagoon, and flow returning back to the ocean out the channel (Figure 3).

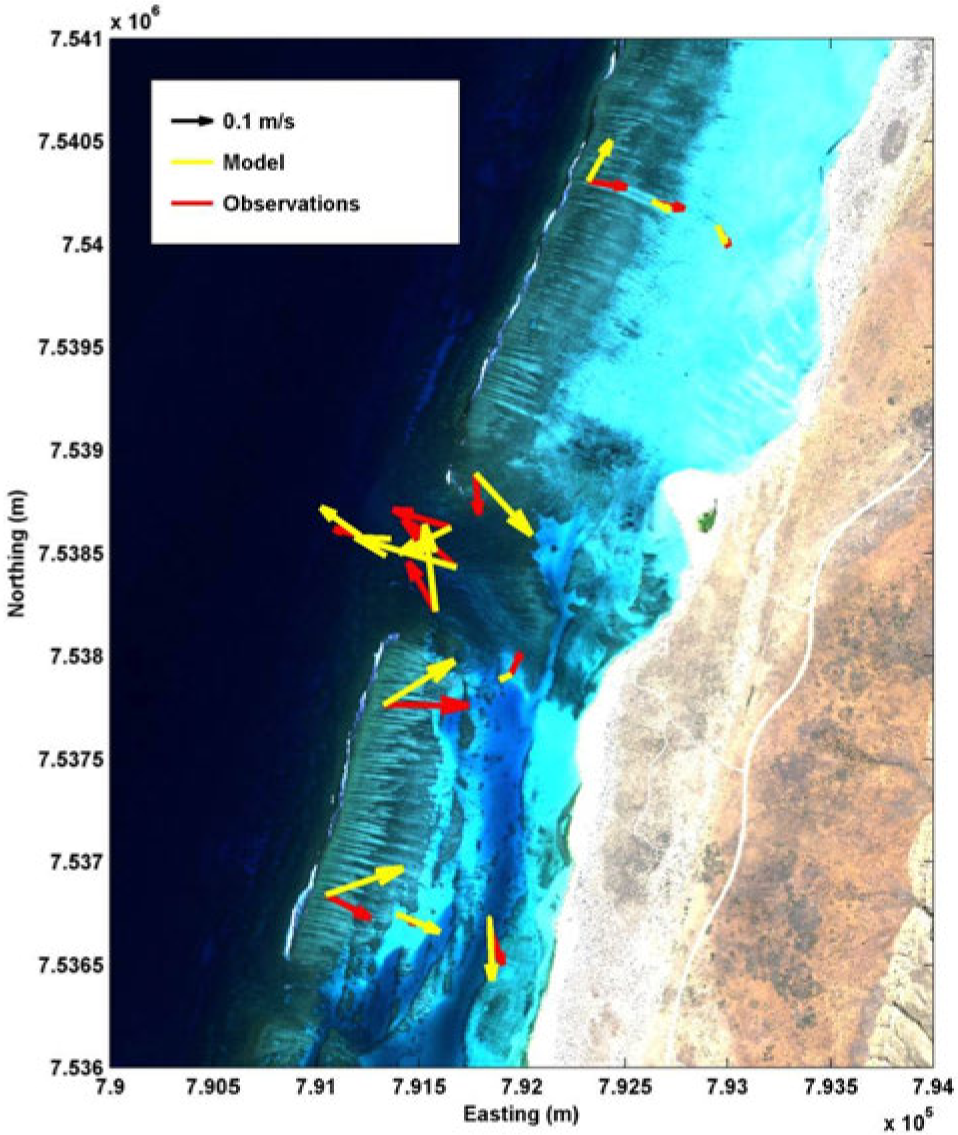

Figure 3 Comparison between the mean (two-week averaged) current vectors predicted from the hindcast model simulations and observed.

Having the validated model, the flushing time (T_f) of the reef was computed over Sandy Bay reefs and lagoons. It varied on average between as little as 3 hours in winter (minimum in Jul-Aug) to as much as 5 hours in the autumn (maximum in Apr). Yet at any time throughout the year, the flushing time can also vary significantly on daily time scales (i.e., frequently ranging from 2-12 hours). This variability in T_f is primarily driven by variability in incident wave forcing (on both seasonal and event time scales). Wave setup on reefs has been observed to increase linearly with the incident wave energy flux (power), which is proportional to square of significant wave height (H_s^2) and wave period (T_p). The alongshore pressure (water level) gradients within the lagoon of fixed geometry would thus also increase proportional to $H_s^2 T_p$. When balanced by quadratic bottom friction (i.e., where the shear stress is proportional to the current speed squared), this predicts that the wave-driven flows within the reef-lagoon system (and hence Q in Eq. 1) should increase proportional to $H_s T_p^{1/2}$. With T_f inversely proportional to Q (via Eq. 1), we would thus expect $T_f^{-1} \propto H_s T_p^{1/2}$, and this prediction is confirmed by the results (Figure 4). Note that over a seasonal cycle, both H_s and T_p increase by ~20% from summer to winter (i.e., H_s from ~1.3 m to ~1.5 m; and T_p from ~13 s to ~15 s). This implies that the seasonal variability in T_f^{-1} is primarily driven by changes in wave height rather than period, given that T_f^{-1} increases linearly with wave height, but only to the power 1/2 with wave period.

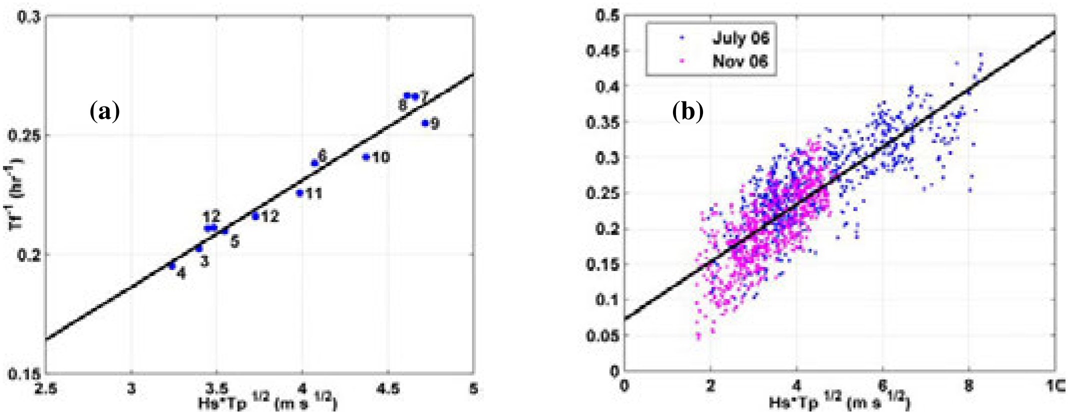

Figure 4. Inverse flushing time T_f^{-1} of the reef-lagoon system as a function of $H_s T_p^{1/2}$. (a) Predictions for different months forced by the seasonal monthly-averaged wave and wind conditions (numbers refer to months from Jan to Dec). (b) Predictions from the two month-long hindcast simulations in 2006. Black lines denote the line of best fit.

The hydrodynamic model of the reef including Sandy Bay and adjacent reefs under different environmental forcing allowed an understanding of the relative roles of waves, tides and wind in the circulation rate (current pattern and intensity) of a section of reef in NMP which are the key parameters in ecological processes including nutrient supply and productivity, recruitment and connectivity as well as the transport of propagules and/or pollutants. The respond of the reef hydrodynamics to different forcing conditions within an average year (seasonality) was also investigated using validated model and can provide further assistance for Ningaloo Park managers for detailed planning and also strategic planning for natural and human related hazard.

Acknowledgements

This work has benefited with support from the Western Australian Marine Science Institution (WAMSI Project 3.5), Australian Research Council Discovery Grant, Australian Institute of Marine Science (field work assistance) and student scholarship from University of Western Australia.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

The results have been published in few journal and conference papers which are accessible online. The raw results such as model outputs do not make much sense as individual results and need to be interpreted along with other results from field and model.

Knowledge Transfer

The results provide useful information for any research/management which needs the knowledge of reef hydrodynamics. This includes assessing safety of high use recreational swimming areas exposed to currents as well as response to oil and other contaminant spills. It will also inform further research on hydrodynamics in this fringing reef system.

6.20 Project 3.5.2: Biological oceanography of NMP- organism-scale nutrient dynamics

Project Leader
Anya Waite (The Oceans Institute, University of Western Australia)

Research Team
Alex Wyatt, Cecile Rousseaux, Nicole Patten, Saskia Hinrichs, Diane Krikke, Ryan Lowe, Jim Falter (The Oceans Institute, University of Western Australia)

Project Overview
The biological oceanography of a coral reef system should be considered within the context of the influence of broader oceanic processes. For example, it is well understood that Ningaloo Reef is supported by the productivity generated in the Leeuwin Current which dominates from autumn through winter as well as nutrients provided by upwelling during the spring and summer seasons. However, there is still limited understanding of the flow of energy across the reef face and its transformation into a healthy and productive reef and lagoon system. This project set out to provide a better understanding of the processes that control the links between the ocean and reef systems and how these impact upon nutrient and energy flow and reef health.

This summary encompasses a larger program of research that extends beyond the project conducted through WAMSI.

Objective
The overall project addressed quantifying food supplied as planktonic particles to the coral community at Ningaloo Reef. The objectives to achieve this were to determine the source of food particles and dissolved nutrients delivered across the reef by regional oceanography and to track ocean particle and nutrient sources in the coral reef food web via biomarkers. Information gained from this study is expected to apply to marine park management questions that relate to nutrient and energy flow across the reef and how this and water movement influences the distribution of biodiversity (including connectivity) as well as the implications for Ningaloo Reef with changes to oceanic patterns and conditions.

Materials and Methods
A detailed field study was undertaken at Sandy Bay, Cape Range National Park in May 2007 and May and November 2008 to measure biological and geochemical components of the water column and reef. This included reef-based sampling to assess the local particle flux from the reef front to the lagoon and changes in particle concentration across the reef top and offshore sampling to assess the oceanic delivery of nutrients to the reef. Within the reef, water column sampling of biogeochemical parameters was conducted along a dominant cross-reef flow path. Stable isotope and fatty acid biomarkers were used to examine species level plankton uptake. For full details on field sampling protocols and analysis see Waite et al (2010).

Key Findings
This research program as a whole demonstrates the links between large scale oceanic processes such as the Leeuwin Current and its seasonal generation of phytoplankton blooms (Rousseaux 2011) to reef health and productivity. Phytoplankton, the main food source for the reef, is supplied over variable daily and seasonal time scales in response to the dynamics of a regional current system dominated by the warm, southern flowing Leeuwin Current (LC) and the sporadic cooler upwelling associated with northward flowing

Ningaloo Current (NC). Seasonal variation was observed through the autumnal and winter phytoplankton bloom supported by the LC which provides a vast mount of nutrition in the form of phytoplankton to the reef. This was followed by a spring/summer nutrient source provided by sporadic upwelling, driven by the upwelling favourable winds at that time of year. Acceleration of the LC in the Austral autumn likely supplies as much phytoplankton to the reef as the upwelling associated with the NC in the austral summer. Thus the reef is functionally dependent on externally sourced ocean productivity which increases the potential scale at which human and climate induced changes may affect reef communities. Processes such as changes in offshore currents and plankton communities require further consideration in reef health.

At the reef scale, wave action over the reef flat drives plankton supply as the reef sucks up the nutrients provided via phytoplankton blooms in the LC. Phytoplankton uptake rates were found to be near the physical limits of mass transfer. This energy is then transformed and released as base nutrients (C and N) available to sustain biodiversity in the reef and lagoon system. These nutrients may feed the lagoon system or may be washed out through reef passages to feed deep water benthic communities or the reef front.

At the organism scale, there is increasing interest in the role that plankton feeding plays in energy budgets, calcification and resilience to stressors which may have implications for maintenance of reef biodiversity.

NMP may be linked to an area of ocean on the order of 1,000 to 10,000 km ^{2} during upwelling and non upwelling periods respectively. The dependence of Ningaloo reef on a large ocean catchment for supply of nutrients has implications for it susceptibility to climate change.

Management Implications

Managers of tropical reef systems may need to consider the larger scale influences of oceanic processes on coastal reef systems, in particular in relation to climate change. Indirect effects, such as changes in offshore currents, such as the LC, may have serious implications for the health of Ningaloo Reef if these effects include disrupting the production and supply of phytoplankton to the reef. Slowing of the LC, or changes to factors that would diminish the seasonal plankton bloom could result in nutrient stress to Ningaloo reef. Similarly, ocean acidification may have long-term implications for phytoplankton communities and changes to ocean biogeochemistry could also interrupt phytoplankton delivery to Ningaloo reef.

This new information and understanding should be taken into consideration in the management of NMP and other tropical marine areas. In particular, oceanic processes and their connection with reef systems should be considered in the timing of activities such as dredging or drilling to minimise negative effects on the reef or catchment that may be linked to seasonal current flow and nutrient supply. Evidence was found in this study of the links between coastal and offshore regions through surface currents. In particular, this study noted that drifters released at Barrow Island ended up at Ningaloo Reef, suggesting NMP may be vulnerable to contaminant spills from these distant locations. This information is different to that used by proponents of the LNG industry in their modeling scenarios.

This project points to a number of research areas where we need further knowledge to fully understand the interplay between oceanic processes and coral reef health and productivity. These include:

- Determining the physical capacity of Ningaloo Reef to uptake nutrients in order to understand the limiting factors in reef productivity.

- Investigating nutrient flow from the reef to the lagoon system and determining where nutrients are taken up in the lagoon, e.g. macroalgae, and the implications this has for predicting macroalgae blooms
- Developing our understanding of how climate change may alter the conditions of the dominant current systems in WA and what impact this will have on production and supply of nutrients to Ningaloo reef.

This information would lead to a better understanding the reef's response to changes in oceanic condition.

Acknowledgements
Elements of this program of research were funded by Wealth From Oceans National Research Flagship Program and by an ARC Grant.

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Data Resources
Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Knowledge Transfer
Findings from this study have application to the management framework for Ningaloo Marine Park as well as for future research. In that regard, the information from this study should have relevance to marine park planners, operational staff with day to day management of the marine park and public safety and research scientists.

6.21 Project 3.10: Assessment of coastal groundwater and linkages with Ningaloo Reef

Project Leader
Lindsay Collins (CUT)

Research Team
Deanna Wilson, Alexandra Stevens (CUT)

Project Overview
Little is known about the groundwater system and its connectivity with Ningaloo reef, but there is sufficient information to indicate that groundwater discharge from the hinterland to the reef system is a significant process which likely has linkages to issues such as stygofauna habitat, water chemistry and biodiversity patterns within the reef lagoon. Exmouth peninsula contains a karst hinterland which, through its conductive nature, means that the groundwater system can be expected to be responsive to recharge and runoff events, tidal oscillations, seasonal variations and storm events. Additionally, groundwater discharge is likely to have significant impact within lagoons for example by delivering nutrients to the reef system at discharge points as has been noted for the Great Barrier Reef. The coastal groundwater lens at Ningaloo is thin, recharge-dependent, and oscillates with the tidal cycle. It very likely does not comprise a stable or significant fresh water supply and sustained pressure on the aquifer at levels above former stock and station uses would most likely result in saltwater intrusion.

Given the above, it is important to have an understanding of the groundwater system, how it functions and where the major discharge points are. This information may prove crucial in planning for any future coastal plain tourism or other developments to ensure that water extraction does not stress the system, nor nutrient inputs to the hydrological system (and thereby the reef ecosystem) impact the biodiversity.

Previous to this project there was little information on the groundwater system of Exmouth peninsula, extending into the Ningaloo Marine Park other than the recognition that it is a karst system likely to have high conductivity. Groundwater system research can be expensive and time consuming, however remote sensing techniques coupled with ground truthing can be applied to begin predicting groundwater pathways and discharge points. This became the basis for the first stage in describing and understanding the groundwater system and the potential for anthropogenic and natural impacts that may affect it and the Ningaloo Reef more broadly.

Objective
The aim of this project was to improve our understanding of the groundwater system underlying Exmouth peninsula and, in particular, its links with the nearshore and oceanic processes supporting Ningaloo reef. This was addressed through the following Objectives

- To characterise the hydrological and geological aquifer system of the western coastal plain of Exmouth Peninsula.
- To characterise the coastal seawater/freshwater interface, its behaviour in relation to seasonal fluctuations, tidal and episodic events (e.g. cyclones) and its physico-chemical structure.
- To determine the pathways of groundwater discharge to the Ningaloo Reef lagoon and physical and/or benthic 'signals' of discharge.

Materials and Methods

This project used remote sensing technology, including hyperspectral data and satellite imagery, as a starting point to create predictive models that would describe the groundwater system along the Ningaloo reef and western coastal plain. However, a number of additional research projects have provided supporting information to our investigation of the groundwater system, some which will expand this project beyond this report and provide additional insight in the years to come on the stygofauna and associated hydrogeological system. Lee (2008) prepared a hydrogeological model for the eastern coastal plain. We used this model to characterise and explain the western coastal geological and groundwater system as the geology and stratigraphy are similar across the Exmouth Peninsula.

A follow on joint project between Curtin University and Western Australian Museum (initiated in 2010) has drilled a series of boreholes at Bundera sinkhole and instrumented them to examine the stygofauna and monitor groundwater flow and chemistry. This project is still underway and will ultimately describe groundwater dynamics and flow as well as the geological controls and aquifer characteristics of the system. Further, this project is planned to undertake at least one full year of monitoring which will include cyclonic activity. This will give a good indication of how the system works in particular after recharge events. Information in this regard will be forthcoming over the next few years.

This project is an initial foray into understanding the groundwater system and does not therefore provide a thorough description of the system. Rather it uses remote sensing and information from other karst environments to predict how the groundwater system at Exmouth Peninsula is likely to operate. In that sense, the results present as many questions and areas for future research as they address. For a fuller description of the project, methods and findings see Collins and Stevens (2010).

Key Findings

The study of carbonate aquifers is challenging and deserves much attention owing to their dynamic behaviour under stressed and natural conditions. The regional hydrogeology of Cape Range is strongly controlled by the central, folded Tertiary limestone, flanked by coastal plain aquifers on both sides of the range. Consequently, groundwater predominantly flows from the centre of Cape Range towards Ningaloo Reef and Exmouth Gulf with relatively steep groundwater gradients near the crest of the range and relatively flat gradients on the coastal plain. Further, the regional groundwater system occurs within a non-homogeneous, connected karstic aquifer system (Allen, 1993).

The groundwater system along the west coast of Exmouth Peninsula is characterised by a thin layer of fresh water over brackish and saline water. (Figure 1) The karst features of the aquifer result in a strong tidal influence that can extend to at lest 1.6 km inland.

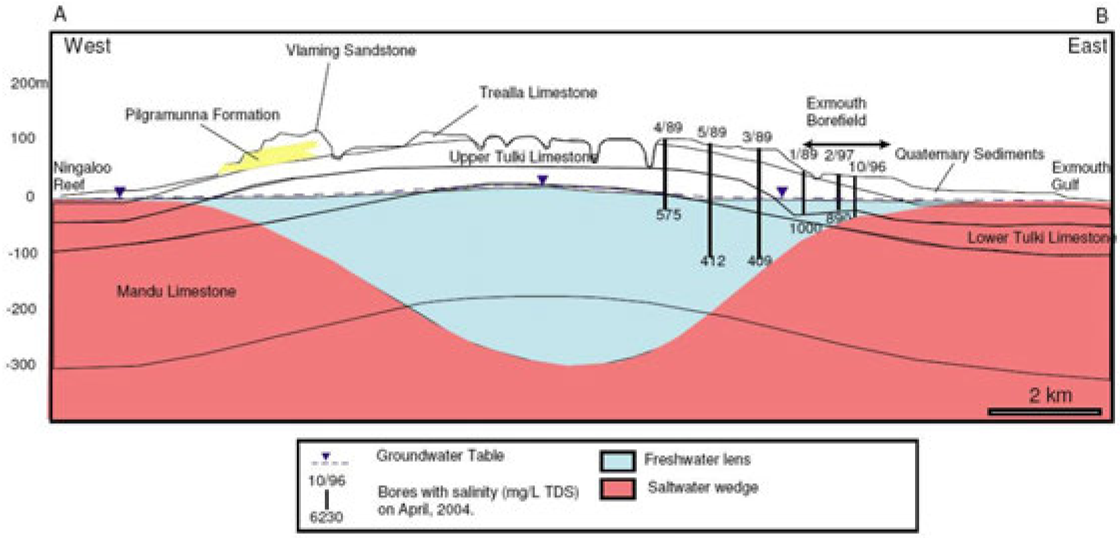

Figure 1 Cross section of the regional hydrogeological units of Cape Range (Modified after Allen, 1993). Shows bores with salinity data from April, 2004 field sampling. Note freshwater and salt water distribution beneath coastal plain and the thinner freshwater lens on the west coast in relation to the east coast.

Similar tidal influences are also noted on the eastern gulf side of Exmouth Peninsula. Overall, the limestone aquifers of Cape Range are in a highly dynamic and fragile state due to the highly permeable fractured and karst limestone set in an arid coastal setting.

Spatial patterns were found in the groundwater data for NMP making it possible to predict areas where groundwater discharge is likely using a combination of fresh groundwater indicators such as well locations, karst, Ficus distribution and stream discharge. A map of the groundwater system has been composed based on the predictive analysis. Further, predictive analysis on hyperspectral data has highlighted a number of 'likely areas' for groundwater discharge and will focus future groundtruthing effort. While it is unlikely that a 'pure' spectral signature exists for groundwater discharge, there may be a combination of signals relating to the benthic cover at and around discharge points which will be dependant on the nature of the groundwater and extent of the discharge.

Sites that are likely to be fluid escape pathways were also identified in the deep waters of Ningaloo Marine Park (70-80m) through project 3.1.1 (Heyward et al this volume) (Figure 2). These sites were characterised by large mounds and pits in the sea bed and are proposed to be seepage points from karst conduits. However, there has been no mapping of the karst system underlying the seabed to confirm these conduits.

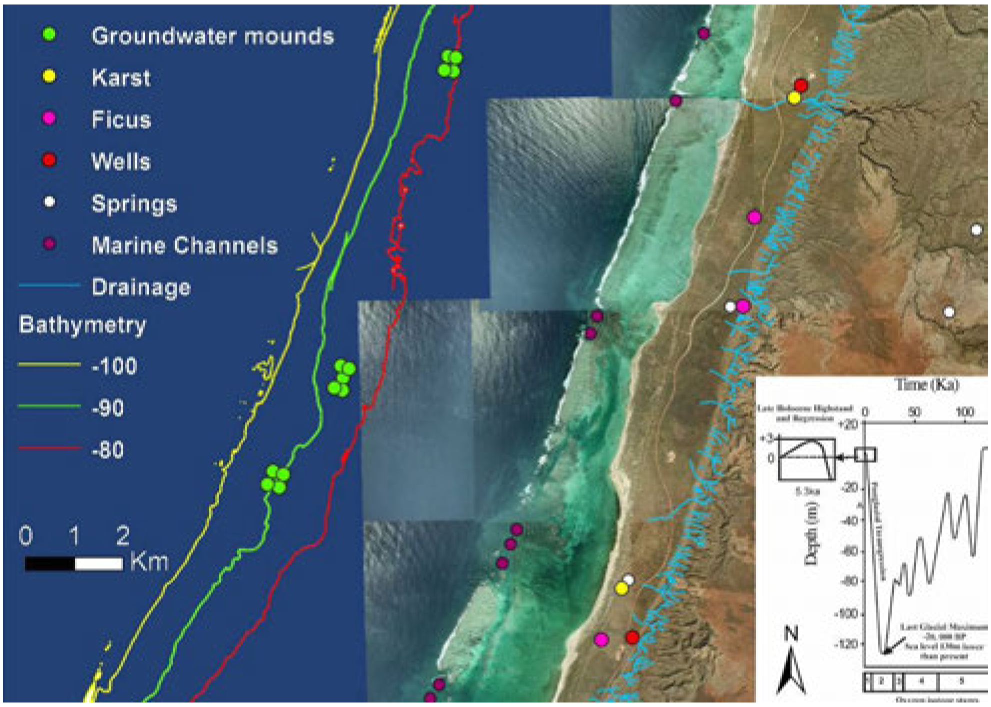

Figure 2 The location of possible submarine groundwater discharge mounds in relation to onshore groundwater indicators. Note proximity to the LGM (~20ka BP) shoreline at ca. -120m. Data on mounds (depth 80-90m) supplied by project 3.1.1.

Implications for management

The outputs of this project include spatial layers and predictive map of the underlying groundwater system including some possible outflow sites in NMP. This information should be used by managers in their assessment of development and human activities within the marine park, Cape Range National Park and more broadly across the Region. Some specific uses for this research are noted below.

Effect of groundwater extraction on the hydrology of the karst system.

Human-induced stresses on an aquifer are exerted primarily through pumping of ground water and pollution. The coastal groundwater lens on the west coast of Cape Range is thin and recharge-dependent, and oscillates with the tidal cycle. The freshwater lens is thinner on the western coast due to the coarser grained sediment making it more susceptible to salt water intrusion (Peterson, 1997) and thickens inland. It very likely does not comprise a stable or significant fresh water supply and sustained pressure on the aquifer at levels above former stock and station uses would most likely result in saltwater intrusion. Salt water intrusion will have, as yet, unknown effects on the karst habitat and stygofauna. Given the complex environment as found by Humphreys et al (1999) in their study of the effects on diving on the Bundera sinkhole even minor change to the karst environment could have a significant effect on the ecosystem.

Any extraction of groundwater on the west coast will need to be undertaken with this in mind. If extraction were to be permitted strict control measures relating to environmental protection would be required such as limits to number of tourist development residents and consideration of alternative water supplies including rain water storage and treatment and reuse of wastewater where possible. Given the thin nature of the freshwater lens, any groundwater exploitation should take place as far inland and within Cape Range as possible in order to mitigate this issue.

Any future usage of coastal groundwater will be subject to legislative controls and EPA approvals, and in some circumstances projects will carry monitoring requirements. Reef managers will need to take careful note of accidental spills and/or violations of license conditions. Current and new sewage infrastructure will be similarly subject to regulation, but greater potential for nutrient spills from storm surge flooding will exist and require monitoring in a climate change future.

This information will be important if any future development or tourism activity is expanded in the coastal plain. Should this occur, care must be taken to ensure that nutrient inputs to the hydrological system are minimised. Further, any groundwater usage proposal would also need careful evaluation in view of the identified supply limitations and fragile nature of the coastal groundwater system. This assessment should include consideration of:

- Proximity to geomorphological features indicative of the groundwater system and likely conduits in the karst syste (e.g. bays adjacent to gorges and channels in the reef system are indicative of water flow areas and will experience a higher impact from any inputs or removals from the groundwater system, and thus should have very limited, if any, infrastructure and development).
- Groundwater use as this is a limited system and any significant use will result in a draw up of more saline water into the groundwater system, impacting on associated fauna and biodiversity;
- Wastewater discharge as this is likely to have an impact on biodiversity and habitats within the Ningaloo reef system, including the lagoons and deep waters.
- Placement of infrastructure such as sewage treatment plants, as their flooding through cyclonic storm surge activity may result in nutrient discharge into the coral reef lagoon. Such risks may increase in the future along with the frequency and intensity of catastrophic events.

Predictions of greater intensity of rainfall events (severe storms/ cyclones) and increases in sea level during climate change carry with them an associated increased risk of coastal erosion, storm surge and flooding. Thus, it may become relevant to increase protection for particular elements of the groundwater system that are vulnerable to human and natural activity. For example, the Bundera sinkhole is a relatively fragile system, vulnerable to human development and activity and represents a unique geological feature in the region. Currently it is located on Commonwealth military land and is therefore relatively protected from disturbance. Should this tenure change, then consideration would need to be given to adequately protecting this site, its unique geomorphologic characteristics and associated biodiversity communities. Further consideration may also be given to sites identified in the marine park as seepage points should they be considered vulnerable to human activities.

There is clearly a need for education on the fragile nature of the coastal groundwater system of Ningaloo reef. Water use facilities (a spa in most rooms) and water consumption in the region’s most recent resort hotel hardly set an example for water conservation in this arid environment, and growth in the region could ultimately be limited by groundwater availability. This project, along with 3.4 (geomorphology, Collins et al this volume) has produced very visual and interesting information on the karst system and how the groundwater system likely functions along Exmouth Peninsula.

The potential influence of groundwater outflows on coral reef systems due to coastal pollution, benthic zonation and productivity, nutrient outflows, salinity variation and dissolved substances calls for ongoing monitoring. As tourism development accelerates on the Ningaloo coast, impacts are likely to become more significant. An understanding of the groundwater system and its hydrochemical properties will become critical for impact assessments especially in light of the unpredictability of our climate change future.

The Bundera sinkhole monitoring site was selected because of the existence of karst and monitoring of stygofauna as an ongoing project by WA Museum. The test site developed at Bundera sinkhole will provide information on the nature of the groundwater system and interactions between groundwater and stygofauna. The data generated will provide a basis for future management planning in relation to these poorly known systems.

In addition to Bundera, this project has identified possible reference sites for potential long-term monitoring to detect changes related to groundwater flow and consequent impacts on the coral reef system. Monitoring would should include measures of water level variation, conductivity, temperature, nutrients and water chemistry.

Research

In addition to natural processes, future urban expansion and coastal plain land use planning and tourist development in NMP will need careful management to ensure that the fragile groundwater system is not over-exploited, and also that nutrient discharges from wastewater or via natural flows do not impact reef biodiversity. Putting the appropriate management measures in place will rely on sound underpinning research.

The key hydrological processes linking the subterranean aquatic habitats and the adjacent marine waters remain poorly understood, and the Bundera Project is an important step in providing such information. Karst aquifers and karst conduits, tidal oscillations, climate aridity and periodic but irregular recharge, are important factors today. In the longer term, climatic shifts and rising sea level impacts will need further evaluation and management responses. It would be useful to extend the borehole system to cover additional geological zones that would allow mapping and understanding of the karst conduit system to offshore. This would be a large and expensive venture, best added onto an existing program of work.

While the initial model developed has been very instructive, it can be improved by further research in several areas. Groundtruthing of the predicted seepage sites will provide invaluable information to refine the spatial predictive models as the more known sites that are available, the more accurately and precisely predictive models can be developed. Further work can be conducted on identifying the spectral signature used in the models to determine whether a standard signature for fresh groundwater in a shallow marine environment can be identified. This analysis could increase the probability of finding fresh groundwater occurrences in the Ningaloo Marine Park.

The underlying karst system is poorly understood and is not mapped for the western Exmouth Peninsula extending offshore to the continental shelf. However, there are indications of groundwater flow and seepage points in the lagoons and along the coastal shelf at 70-80m depth. Research should focus on developing our understanding of the conduit system that exists within the karst, including mapping the karst system and the fluid escape sites. This should include mapping of the network of subtidal caves present in Cape Range National Park based on existing information on cave location and particular features held by spelio groups.

There are some indications that beaches preferred by turtles for nesting may also be associated with groundwater outflow areas. Further research into the relationship between turtle preferences and the system would be useful so that groundwater system integrity may be taken into consideration in the long-term conservation of marine turtles where appropriate.

Acknowledgements

This research represents a WAMSI project that was expanded through additional funding and research resources. The hydrological model of the eastern coastal plan was funded

through Curtin and conducted by Sam Lee (Lee 2008). The Bundera Project led by Dr Bill Humphreys and funded by WAM included drilling and instrumenting a borehole transect at Bundera sinkhole to monitor stygofauna and groundwater within the western coastal plain at Bundera. The latter expands upon the WAMSI project and will add further insight in the future into the stygofauna of the region.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/) (See Section 10, Table 1).

Datasets and formats include GIS referenced spatial map of groundwater indicators.

Knowledge Transfer

This is a Baseline study providing information on Ecological values and ecosystem processes that support NMP. As such it is applicable to several areas of management within DEC including Planning for both terrestrial and marine parks as well as research and monitoring activities. In addition, this information will be useful to other agencies responsible for regional and local planning and coastal development.

6.22 Project 3.9: Valuing the intangible assets of marine reserves: a choice modelling application to the Ningaloo and proposed Ngari Capes Marine Parks

Principle Investigator
Abbie Rogers (nee McCartney), PhD candidate.

Research Team
Supervisors: Prof. Michael Burton and A/Prof. Atakelty Hailu, School of Agricultural and Resource Economics, University of Western Australia.

Project Overview

NMP is an important public asset to many West Australians. In reflection of other marine parks along our coastline, Ningaloo is important for many recreational and commercial endeavours, such as recreational fishing and eco-tourism, both of which make an important economic contribution to the State. The reserve is also recognized for its biodiversity, which arguably may have higher values associated with its existence than the values it generates through recreation and commercial aspects; however, it is difficult to compare the value of biodiversity existence against other measurable economic impacts.

Economic non-market valuation techniques exist that are able to quantify intangible values for assets such as biodiversity in dollar terms, comparable to the measurable recreational and commercial gains. The choice modelling (CM) technique, in particular, is able to capture 'non-use' values. These values encompass the intrinsic existence and conservation values that people may hold for the environment. Non-use values have been under-represented for marine parks, and coral reef systems in general (Spurgeon 2004), despite their obvious importance – often marine reserves are gazetted with the primary objective of conserving the ecological components within, suggesting that information regarding non-use values of the reserve should be a vital ingredient for decision making. CM could offer a means of explicitly identifying marine non-use values that can then be weighed against other economic costs and benefits of proposed policies.

This study aims to investigate the suitability of using CM to value ecological components of NMP. In doing so, two novel elements are examined: (1) preferences held by both the general West Australian community and Australian marine science experts are measured and compared; and (2) values regarding both the conservation and management of the ecological components are measured.

The comparison of public and expert preferences in (1) offers an important insight as to whether expert opinion can be solely relied upon to guide marine reserve policy. Experts often inform environmental policy decisions (Adamowicz 2004). This is a cost-effective means of decision making, and indeed expert consultation is required in terms of technical and feasibility advice for policy. However, experts may not adequately represent the value judgments of the public. If values and preferences for the conservation of marine reserves diverge between public and expert communities, then public consultation (such as CM) becomes essential to inform policy decisions.

With respect to (2), traditionally CM focuses only on the value of an outcome (i.e. the conservation value), and not the management process by which that outcome is achieved. However, by also targeting preferences for management, policy relevant information can be generated to help guide the most appropriate means for implementing conservation measures (e.g. Johnston and Duke 2007).

A second case study, the proposed Ngari Capes Marine Park in the south-west of Western Australia, is also investigated. There is a lower level of public awareness associated with the Capes in comparison to Ningaloo: the proposal status of the Capes means people are generally unaware that the area is to become a marine reserve; and the publicity focus of the Capes region is not predominantly aligned with its marine resources as is the case for Ningaloo. Investigating differences in awareness allows further insight into instances where preferences of the public and experts may diverge.

A brief description of the project methodology follows, along with the key results, conclusions and policy implications. A focus is maintained on the Ningaloo case study here; readers are referred to McCartney (2011) for further detail on all aspects of this study, particularly the Capes case study results.

Materials and Methods

CM is a survey based technique, where respondents are faced with hypothetical 'choice scenarios' that require the respondent to make trade-offs between competing policies that contain a package of measures. Each choice scenario contains a number of hypothetical policy options (usually about three or four), and a set of 'attributes' or features of interest. The attributes are each defined by a number of different levels. The level of each attribute is varied across each policy option, and respondents must select their most preferred option according the levels of the various attributes offered, thereby creating the trade-off scenario. One of the attributes included in each scenario reflects the cost of the policy option, and one of the options in each scenario reflects the current situation, or status quo, which is usually a zero cost option. The inclusion of the cost attribute is important – it specifies a (hypothetical) cost to the respondent to mimic the reality that the provision of additional goods or services (such as improved conservation of Ningaloo) will come at a price. An example of a choice scenario used in this study is provided in Figure 1.

Choice Set 1 - **Consider the following options. Assuming these are the only options available to you, which one would you be most likely to choose and which one would you be least likely to choose?** ***Please keep your financial circumstances in mind while answering.***

	OPTION 1 status quo	OPTION 2	OPTION 3	OPTION 4
Conservation of coral reef	0% more coral	10% more coral due to 10% new no go zones	5% more coral due to 5% new no go zones	0% more coral
Conservation of target fish stocks	0% more fish	10% more fish due to 15% increase in sanctuary zones	5% more fish due to 2 month seasonal fishing closure	0% more fish
Conservation of turtle populations	0% more turtles	10% more turtles due to 6 extra fox bait zones	10% more turtles due to 100km beach closure	0% more turtles
Conservation of whale shark population	0% more whale sharks	0% more whale sharks	2% more whale sharks due to Government donating $1,000,000 to their international conservation	5% more whale sharks due to 50% reduction in whale shark tours
Cost to you per year	$0	$20	$60	$80
Most preferred option:	○	○	○	○
Least preferred option:	○	○	○	○

Figure 1: A choice scenario from the Ningaloo CM survey asking respondents to select their most and least preferred (hypothetical) policy options.

The attributes in this study were formed from four ecological components of Ningaloo, plus a cost attribute. The ecological components are anticipated to reflect the non-use values of the marine park. However, it should be noted respondents' values for these attributes may also incorporate some use value components, for example, through recreational use.

Three of the four attributes were selected based on them being Key Performance Indicators (KPIs) in the marine park's Management Plan (MPRA 2005). KPIs are recognized as being important in terms of ecosystem function – they are attributes that are monitored closely by scientists so that their status can be used as a proxy for overall ecosystem health. Specifically, the three KPI attributes were: coral; target fish stocks (i.e. the finfish in the marine park that are most commonly sought after and caught by recreational fishers); and marine turtles. The fourth attribute included was whale sharks, representative of iconic megafauna.

The levels of each attribute were comprised of two components: conservation outcome levels, and management process levels. For each of the coral, fish and turtle attributes, the conservation outcome levels were defined as either a 0%, 5%, or 10% increase to their population (see Table 1). For whale sharks, the levels were 0%, 2% and 5% increases to their population.

The management process levels were defined separately for each attribute, based on future potential management strategies or strategies that could alleviate particular threats to the attribute. Two different management processes were defined for each attribute – management types T1 and T2 (see Table 1). Although the management processes varied across attributes, a common feature was that in every case management type T1 was more restrictive on human use of the marine park than management type T2.

The conservation and management levels were then coupled together, so that each percentage improvement in conservation was achieved by one or the other of the two management processes. Table 1 shows these couplings, resulting in five distinct levels for each attribute. Note that the *quantity* of management increases along with increasing conservation outcome, and where there is no improvement in conservation (i.e. the 0% level) no management process is specified.

Table 1: Ecological attributes and their levels comprised of a conservation outcome and management process.

Coral (KPI)
0% more coral
5% more coral due to 5% new no go zones (T1)
5% more coral due to 7% increase in sanctuary zones (T2)
10% more coral due to 10% new no go zones (T1)
10% more coral due to 12% increase in sanctuary zones (T2)
Target fish stocks (KPI)
0% more fish
5% more fish due to 2 month seasonal closure (T1)
5% more fish due to 10% increase in sanctuary zones (T2)
10% more fish due to 3 month seasonal closure (T1)
10% more fish due to 15% increase in sanctuary zones (T2)
Marine turtles (KPI)
0% more turtles
5% more turtles due to 50km beach closure (T1)
5% more turtles due to 3 extra fox bait zones (T2)
10% more turtles due to 100km beach closure (T1)

10% more turtles due to 6 extra fox bait zones (T2)
Whale sharks (iconic megafauna)
0% more whale sharks
2% more whale sharks due to 25% reduction in whale shark tours (T1)
2% more whale sharks due to Government donating $1,000,000 to their international conservation (T2)
5% more whale sharks due to 50% reduction in whale shark tours (T1)
5% more whale sharks due to Government donating $2,000,000 to their international conservation (T2)

The cost attribute was specified as an annual environmental tax, taking on levels of $0, $20, $40, $60 and $80. The $0 level was only ever associated with the status quo option in the choice scenario, where the conservation of all ecological attributes reflected a 0% level (i.e. no change to the current situation, therefore no additional financial investment required).

In CM, an experimental design is used to arrange the attribute levels across options and choice scenarios. Efficient designs can be created using computer algorithms to ensure that attributes and their levels are not correlated with other attributes/levels. Efficient designs were generated for the survey in this manner, and respondents were each faced with five choice scenarios for Ningaloo (and five for the Capes marine park in the same survey).

A number of sample splits were included in the design to address the investigations into public versus expert preferences, and the inclusion of management processes in the choice model, as described in Table 2. Within the public samples, three different information versions were applied. That is, different amounts of information were used to define the ecological attributes, with the hypothesis that as members of the public became better informed their preferences may converge upon those of the experts. A fourth public sample, the outcome-only sample, had attribute levels that only reflected the conservation outcomes and no management process was specified (e.g. levels of 0%, 5%, 10% conservation improvement, with no link to management). This sample contained the medium level of information, so that it would be comparable to the public M sample for the purpose of investigating the inclusion of management processes. With the addition of the experts, five split samples resulted.

Table 2: Survey samples according to the target population, information version, and attribute level components, with sample size noted.

Sample	Population	Information level	Ecological attribute level components	Sample size
Low information (L)	Public	Low	Conservation outcome & management process	251
Medium information (M)	Public	Medium	Conservation outcome & management process	255
High information (H)	Public	High	Conservation outcome & management process	249
Outcome-only (O)	Public	Medium	Conservation outcome only	152
Expert (E)	Expert	High	Conservation outcome & management process	90

The survey was conducted during July-August 2008 for the public samples, and December 2008-August 2009 for the expert sample, via a web-based survey. Table 2 shows the usable sample size collected for each survey split. Comparison with the

Australian Bureau of Statistics Census 2006 data shows that the public sample was representative of the West Australian population at the time.

The data were analysed according to Random Utility Theory, using a mixed multinomial logit model. Individuals derive utility, or satisfaction, from an outcome (e.g. from the conservation outcomes in the choice scenario options). We can observe, and measure, some of this utility based on the choices that respondents make in the choice scenario. However, some utility remains unobservable; for example, in this survey we specify four ecological attributes, but in reality there are many more attributes that define Ningaloo (both ecological and otherwise), and we do not know what respondents might be thinking about these. Random Utility Theory suggests that we can model an individual's preferences by accounting for this unobservable utility. The mixed multinomial logit is one means by which we can do this. It estimates the probability that an individual will choose one particular policy option over another, and unpacks the marginal utility associated with each attribute and its levels. We can then take the (negative) ratio of an ecological attribute coefficient (i.e. the marginal utility for a particular attribute level) to that of the cost coefficient and calculate a dollar value. This value represents how much an individual is willing to pay for a given outcome. Readers are referred to Bateman *et al*. (2002), Hensher *et al*. (2005) and Train (2009) for an overview of CM theory and analysis.

Key Findings

For the purpose of brevity and clarity, only select results and key outcomes are discussed here. For a full discussion of results, readers are directed to McCartney (2011).

The first approach in modelling the data was to consider how various samples may be combined. Instances where different sample data can be pooled are indicative of preference homogeneity. Of the five samples (see Table 2), the following combinations were possible:

1) As part of the public versus expert preference investigation – the public low (L), medium (M), and high (H) information samples, and the expert (E) sample could be combined; referred to as the N_LMHE model.
2) As part of the management process investigation – the Ningaloo medium (M) information (where management processes *were* specified) and outcome-only (O) (where management processes *were not* specified) samples could be combined in a manner where it was assumed that preferences for conservation outcomes that are achieved using management type T1 from the M sample data are equivalent to conservation preferences in the O sample data, while conservation preferences under management type T2 (M sample) are different; referred to as the N_MO model.

These sample combinations provide two key results. First, we discover that the public and experts hold similar (homogenous) preferences for the ecological attributes at Ningaloo, given that all of the public information (L, M and H) and expert samples can be combined. Second, the inclusion of management processes in the choice model has had an impact on conservation preferences. Not only do we find that people hold significantly different preferences for management types T1 and T2 within the public medium information sample, but we also find that respondents from the sample with unspecified management (outcome-only) behave as if they have preferences that are similar to the preferences that respondents from the medium information sample have for the more restrictive management process, T1.

It should be noted, that in the parallel analysis of the proposed Capes Marine Park (which followed an identical methodology as for Ningaloo), a similar combination was possible for the medium information/outcome-only samples, implying that management process again had an impact. However, with respect to the public and expert sample comparison, although the public information variants could be pooled (i.e. low, medium and high information samples), the expert sample valued the Capes attributes differently to the public samples.

With the sample combinations in place, socio-demographic information was then integrated into the models. That is, an individual's utility for an attribute may depend on their particular characteristics (e.g. gender, age, experience with the marine park or its attributes, the way in which they interpreted the choice scenarios, etc.), which can be included in the model to explain preference heterogeneity. Individuals' willingness to pay was then estimated for each attribute, dependent on any significant socio-demographic variable interactions (Tables 3 and 4).

In the N_LMHE model, people that stated they ignored a particular attribute in the choice scenarios[11] intuitively were generally not willing to pay anything to conserve it, with dollar values not significantly different to zero in most cases (Table 3). All other individuals were willing to pay to protect the ecological attributes. People were willing to pay the most to protect the coral attribute, while the whale shark attribute was associated with the lowest willingness to pay values in most cases. Most of the time, people were willing to pay more to conserve the attribute if the less restrictive management type T2 was in play, rather than T1.

Table 3: Willingness to pay for conserving the ecological attributes in the N_LMHE model, according to management type and socio-demographic interactions.

	$/year/individual	
Increase in coral populations	**5%**	**10%**
T1: No go zone management		
- If did not ignore the coral attribute	85***	92***
- If did ignore the coral attribute	-5	45*
T2: Sanctuary zone management		
- If did not ignore the coral attribute	86***	108***
- If did ignore the coral attribute	58**	56**
Increase in fish populations		
T1: Seasonal closure management		
- If did not ignore the fish attribute	65***	75***
- If did ignore the fish attribute	14	42*
T2: Sanctuary zone management		
- If did not ignore the fish attribute	76***	76***
- If did ignore the fish attribute	7	16
Increase in turtle populations		
T1: Beach closure management		
- Have not been on beach with 4wd before, and did not ignore the turtle attribute	66***	81***
- Have been on beach with 4wd before, and did not ignore the turtle attribute	37**	32*
- Have not been on beach with 4wd before, and did ignore the turtle attribute	27	23
- Have been on beach with 4wd before, and did ignore the turtle attribute	-1	-25
T2: Fox baiting management		
- Have not been on beach with 4wd before, and did not ignore the turtle attribute	62***	74***
- Have been on beach with 4wd before, and did not ignore the turtle attribute	48**	50***

[11] That is, in CM, people sometimes use decision rules to simplify choices where they may not consider a particular attribute while selecting options.

- Have not been on beach with 4wd before, and did ignore the turtle attribute	13	16
- Have been on beach with 4wd before, and did ignore the turtle attribute	-1	-9
Increase in whale shark populations	**2%**	**5%**
T1: Tour reduction management		
- If did not ignore the whale shark attribute	53***	53***
- If did ignore the whale shark attribute	-7	-4
T2: Government donation management		
- If did not ignore the whale shark attribute	62***	70***
- If did ignore the whale shark attribute	-31*	-28

Note: ***, **, * denotes significance at the 99%, 95% and 90% level of confidence respectively.

The turtle attribute presents an important socio-demographic interaction in the N_LMHE model – individuals who four wheel drive on the beach at Ningaloo are not willing to pay as much for turtle conservation as other individuals (when the attribute was not being ignored) (Table 3). This is particularly true when conserving turtles using management T1, which is a beach closure that would preclude access to the beach for this user-group.

In the N_MO model, no socio-demographic variables were significant in explaining preferences, so the dollar values for each attribute are estimated according to management type only (Table 4). Once again coral is the most highly valued attribute to conserve and whale sharks the least. This order is consistent with the willingness to pay amounts in the N_LMHE model.

Table 4: Willingness to pay for conserving the ecological attributes in the N_MO model, according to management type.

	$/year/individual	
Increase in coral populations	**5%**	**10%**
- T1 & T3: No go zone management & unspecified management	77***	86***
- T2: Sanctuary zone management	72***	100***
Increase in fish populations		
- T1 & T3: Seasonal closure management & unspecified management	56***	67***
- T2: Sanctuary zone management	58***	67***
Increase in turtle populations		
- T1 & T3: Beach closure management & unspecified management	59***	64***
- T2: Fox baiting management	45***	64***
Increase in whale shark populations	**2%**	**5%**
- T1 & T3: Tour reduction management & unspecified management	43***	44***
- T2: Government donation management	53***	51***

Note: ***, **, * denotes significance at the 99%, 95% and 90% level of confidence respectively.

Management Implications

The policy implications of these results are discussed with reference to the parallel Capes Marine Park study (see McCartney 2011). The primary conclusions and their implications are as follows:

- *The general public and marine experts value the ecological components of Ningaloo similarly.*
  There is a convergence of marginal utilities for attributes between the public and experts in the N_LMHE model. This suggests that, in the case of Ningaloo, expert opinion may be an adequate and cost-effective means of directing policy decisions.
  However, in the case of the Capes, clear divergence exists between the public and marine science experts, suggesting that in some instances public consultation methods (such as CM) will be required to collect data on public preferences to ensure public opinion is adequately considered in policy decisions.

- *Knowledge and awareness factors are (at least in part) responsible for driving preferences for marine park conservation.*
  Although the varying information levels within the survey did not impact greatly on public preferences, other evidence is found to support the theory that knowledge factors affect preference formation. In particular, public awareness of Ningaloo appears to have played a role in the convergence of public and expert attribute values.
  In terms of policy, this conclusion implies that in future instances of conservation preference divergence between the public and experts, it will be important to capture whether the divergence is due to a true divergence in values, or due to a lack of public awareness and understanding (as may be the case for the divergence apparent in the Capes case study). In the event of the latter, it may be desirable to educate the public on a potential policy rather than use their uninformed preferences to drive conservation decisions.

- *Management process does have an impact on marine conservation preferences.*
  The N_MO model specification, and the reaction of individuals who four wheel drive to turtle management and conservation, shows that management processes do significantly impact on preferences. This information is particularly useful in terms of garnering community support for conservation policies. Where competing management processes are being considered in conjunction with a proposed policy, knowledge about the preferred method for implementation of the policy (which can be gathered through CM) can assist its acceptance by the community.

- *Less restrictive management forms are typically preferred.*
  Intuitively, individuals tend to be willing to pay more for conservation under a management regime that is less restrictive on human activities within the marine parks. Thus, if an unrestrictive management regime is considered cost-effective for a proposed policy, it could be generalised that it is appropriate to implement.

  However, in some cases more restrictive management processes may be more cost-effective, but the community may prefer to pay the difference to implement a less restrictive management form instead. In instances such as this, approaches such as CM can be used to determine willingness to pay for conservation outcomes under competing management processes, and in turn determine which should be implemented.

- *Management has welfare implications for particular societal demographics.*
  Individuals who four wheel drive at Ningaloo are willing to pay less for turtle conservation under a beach access restriction management when compared to other individuals, as the management process directly restricts their ability to partake in their chosen activity. This result implies that there is scope for particular demographics to be adversely affected by proposed management for particular policies. In suspected cases, techniques such as CM could be used to determine if welfare is negatively impacted and ensure appropriate compensation.

- *The public and expert communities positively value the conservation of ecological components of Ningaloo.*
  Overall, the ecological attributes for both Ningaloo and Capes were valued positively. Future policy should be aimed at ensuring the continued protection of these attributes.

- *Choice modelling is an appropriate method to estimate the intangible values of marine reserves.*
  Significant and informative values were estimated for the intangible ecological components of Ningaloo and Capes, suggesting that CM is an appropriate technique to collect information on public preferences for marine conservation in future.

Further research
Different conclusions arise from the NMP and Capes investigation into public versus expert preferences. For NMP, attribute values converge; for Capes, they diverge. Here, we suggest that one reason for this conflicting result is the level of public awareness associated with each marine park – the public are more aware of Ningaloo, hence more knowledgeable and likely to form preferences similar to the experts. However, another possibility is that, in the case of Ningaloo, the most ecologically important attribute in terms of ecosystem function, coral, is also a visually attractive attribute[12]. The experts may have been valuing coral highly for its functional abilities; the public for its aesthetic appeal. Further research to establish the underlying reasons for preference divergence would be useful, that is, to determine if divergence is due to a true divergence of values or a lack of awareness. This could be achieved by repeating the Capes experiment after public awareness of the proposed marine reserve has improved, or by investigating a third case study that examines another reserve with minimal public awareness but visually attractive attributes.

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[12] The attributes for the Capes were selected based on ecological similarity to the Ningaloo attributes, but, visually, may be less appealing (e.g. seagrass was selected as an attribute in place of coral).

Project 3.9 Student Project - McCartney

6.23 Project 3.9: Oceanographic forcing of phytoplankton dynamics in the waters off north Western Australia

Principle Investigator
Cecile Rousseaux

Research Team
Anya Waite, Ryan Lowe, Peter Thompson (The University of Western Australia)

Project Overview

Off north west Australia, the Leeuwin Current, an anomalous poleward flowing eastern boundary current, flows adjacent to Ningaloo Reef, Australia's longest fringing coral reef. In this project, the seasonal variation of chlorophyll *a* and nutrient concentrations were first investigated in the waters off Ningaloo Reef at the mesoscale, i.e. scales of 10s to 100s of km. Then the local data collected from two intensive near-coastal field experiments off Ningaloo Reef were used to investigate the seasonal variation in phytoplankton size structure adjacent to the reef and the mechanisms supporting primary production. Finally, we quantified the transfer of primary production to the microzooplankton, both near Ningaloo Reef and along the broader Western Australian coast.

Specifically, the four objectives addressed by the research conducted as part of this thesis were:

1. To characterise the seasonal variability of nutrient and chlorophyll *a* concentrations off the north west coast of Australia.
2. To identify the processes driving the seasonal variability in nutrient and chlorophyll *a* concentrations off the north west coast of Australia.
3. To investigate the differences in phytoplankton community, primary production and nutrient uptake between a period of high- and low-flow of the Leeuwin Current in the waters off Ningaloo Reef.
4. To estimate losses of primary production due to microzooplankton grazing in the waters off the west coast of Australia.

The goal of this research is to understand the processes offshore of Ningaloo Reef that support the production of particulate organic matter that may be available to sustain the reef. This understanding provides the basis to predict the health of the reef under climatic stresses such as El Niño and La Niña events.

Key Findings

Using chlorophyll *a* estimated from satellite-derived ocean colour and *in situ* field observations we identified the existence of a autumn phytoplankton bloom in the waters off north west Australia. In autumn, a combination of the accelerating Leeuwin Current and net surface cooling lead to a significant deepening of the mixed layer depth down to ~100 m (Figure 1). This deepening also coincided with increased nutrient and chlorophyll *a* concentrations in the euphotic zone. We conclude that the MLD deepening is the mechanism driving the phytoplankton dynamics in the waters off Ningaloo Reef through the replenishment of nutrients in the surface waters autumn. In both spring and autumn the size-fractionated phytoplankton concentrations and community diversity, as well as nutrient uptake rates, were quantified. In autumn, the concentration of large-sized phytoplankton increased. Ammonium uptake was always greater than nitrate uptake. In autumn, nitrate uptake was relatively great at 30 % of the total dissolved inorganic nitrogen uptake. For a bloom to develop nutrients must be available at sufficient concentrations; however, grazing by predators can also control phytoplankton populations suppressing the development of a bloom. Theory suggests that a deepening mixed layer may result in a reduction in grazing pressure through dilution. The findings of this study showed that grazing rates did not decrease with the deepening of the mixed layer depth and therefore this theory did not hold for the waters off Western Australia. Instead growth rates were positively correlated with the mixed layer depth which further suggests that the mixed layer depth deepening is the key mechanism allowing net phytoplankton growth. The findings of this study show that there is likely to be substantial seasonal variation in the net production of offshore particulate matter and that this is likely to impact on the productivity of Ningaloo Reef itself.

Management Implications

This thesis was aimed at improving our understanding of biophysical coupling at different spatial and temporal scales, in particular focusing on processes occurring in the waters off Ningaloo Reef. Estimating the magnitude and variability of the potential food available to the reef, e.g. the particulate and dissolved matter in offshore waters is central to the sustainability of the reef system.

Field sampling provided insights into the effects the seasonal variation in physical parameters had on the phytoplankton size structure. Large-sized phytoplankton within the MLDs were more abundant in autumn compared to spring. Previous studies conducted in the waters off Ningaloo Reef focused on the spring and summer months, therefore the existence of the relatively greater concentration of large-sized phytoplankton in autumn compared to spring had remained undetected. The temporal variability in phytoplankton concentrations and size-structure off Ningaloo Reef is likely to have important implications for higher trophic levels. The presence of large phytoplankton favours a food-web leading to abundant herbivores (Ryther 1969). Ningaloo Reef is one of the few regions in the world where whale sharks congregate regularly. The available evidence suggests that they aggregate off Ningaloo Reef to exploit a seasonal and localised abundance of food (Taylor 1994). The increasing chlorophyll *a* concentrations may lead to increasing zooplankton concentrations which may explain the congregation period of whale sharks between March and June and during La Niña years.

We suggest that future studies aim at understanding and quantifying the variability in MLD and chlorophyll *a* concentrations during El Niño versus La Niña events. We would expect that during El Niño events, when the alongshore current has been reported to decrease, the MLD would be shallower and this would result in lower nutrient concentrations in the surface waters and therefore less phytoplankton concentration. However, this is still speculative and would need to be confirmed by future studies.

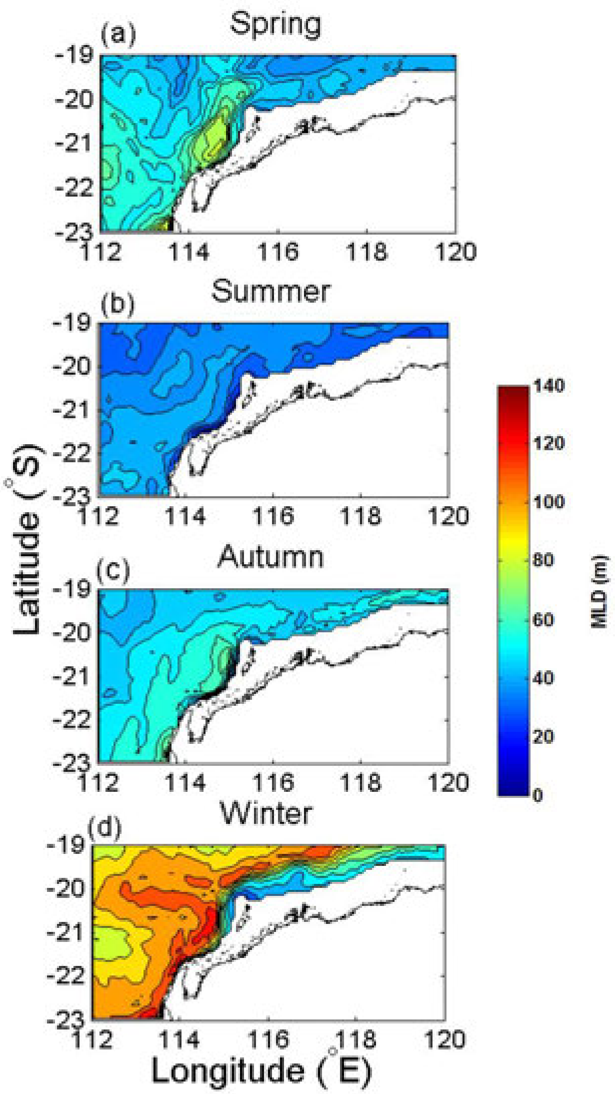

Figure 1 Contour plot of the average MLD (in meters) derived from Bluelink for the year 2007 for (a) spring (September-November), (b) summer (December-February), (c) autumn (March-May) and (d) winter (June-August). Areas with depths shallower than 50 m are blanked.

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/).

6.24 Project 3.9: Foraging and population ecology of manta rays within NMP

Project Leader
Frazer McGregor (Murdoch University)

Research Team
Mark Meekan (AIMS)

Project Overview
Manta Rays have become an important tourism icon within NMP, however little is known of their habitat use and ecology. This project in an effort to better protect manta rays and their critical habitats from over use, has aimed to determine base line population information as well as what attracts manta rays to certain high use areas of the park. Photographic records have been used to determine the demographics of the population, whilst collection of plankton throughout the area has determined in part, the reasons for any seasonal aggregations. As the largest year round planktivore, manta rays are a significant predator within the Park ecosystem. As such, knowledge of where they sit in the local food chain is of great importance and has been investigated using a combination of tissue samples and various prey items. These same tissue samples will also be used for genetic analysis to help determine relatedness within the entire west coast population. Acoustic telemetry has also been used as part of an Australia wide study (AATAMS) to determine the duration of habitat visitation and the extent of travel along the park.

Manta rays, as with other large sharks and rays, have been shown globally to be vulnerable to human impacts such as fishing, habitat loss and tourism, which at present are relatively low within NMP. As prey-specific predators who target the larvae of many reef animals present in plankton, the presence or absence of manta rays over time may be a key indicator of the seasonal health of the tropical reefs they inhabit.

With human pressures increasing within NMP it is important to obtain baseline ecological information such as population size and habitat use. Suitable management of this iconic animal requires an understanding of residence times, seasonal behaviours and effect of disturbance, all of which are addressed in this project.

As the largest year-round consumer of plankton, manta rays are a significant predator within the NMP ecosystem. Knowledge of where they sit in the local food chain (using a combination of manta tissue and samples of various prey items) will give us a better understanding of their dependence on plankton provided by the Ningaloo Reef relative to the open ocean. Tissue samples will also be used for genetic analysis to help determine linkages within the entire west coast population.

Materials and Methods
Photographic records of individuals with unique markings have been used to determine the demographics of the population, while the collection of microscopic plankton throughout the area has confirmed that the presence of food is one of the main reasons for seasonal aggregations of manta rays.

Acoustic tracking has been used as part of an Australia wide study (the Australian Animal Tracking and Monitoring System) to determine habitat use and movement patterns within the park for a number of individuals.

Key Findings

The 500+ manta ray population recorded so far is comprised of a small resident group of largely mature females and a large seasonal transient population of mature males and juveniles. The core group regularly visit oceanographically unique areas to target very specific pulses of what may be endemic plankton, as well as seasonal larvae of 'reef resident' benthic crustaceans. It appears that this core group which support tourism year round, may be the key to introducing new animals to highly productive or key areas during courtship activities, or during seasonal pulses of prey. Tagging data has some individuals utilising the entire park over a month period, as well as diving to over 100m depth outside state controlled waters.

To date over 500 manta rays have been identified in NMP, including a small 'core' group of mainly mature females who appear to be resident year round in the park and a large seasonal transient population of mature males and juveniles.

Preliminary information gathered from the acoustic tags demonstrated that some transient individuals travelled throughout the entire park within a single month possibly searching for seasonal pulses of food, whilst several animals (both resident and transient) were found to travel outside the park into Commonwealth waters and to dive to depths greater than 100 metres.

The core group regularly visits oceanographically unique areas where tides and currents produce large areas of slack water. Here, they target pulses of plankton, as well as seasonal larvae of 'reef resident' sea-floor crustaceans such as crabs and prawns. The transient population arrives en-masse in late summer/early fall to make the most of abundant prey attributed to coral spawning events.

Photographic identification shows that the local tourism industry, which operates year round, interacts mainly with the core group of resident animals. However new animals are also encountered in highly productive and often cryptic key areas during courtship activities, or during seasonal pulses of prey.

Management Implications

Manta ray responses to human interactions are being monitored over time to determine if anecdotal reports of changing behaviour are happening. It appears that the level of disturbance and the success of the in-water interaction with manta rays depends on the original behaviour of the manta. For example, if an animal is feeding on high density prey it is rarely disturbed but an individual which is sporadically feeding, being 'cleaned' by wrasse or engaged in courtship behaviour is easily disturbed.

This research will impact upon the accepted consultation strategies for marine park management. If the research suggests that the preferences of the public and experts are similar, experts can be used as an adequate and cost-effective means of representing public interests in policy and management decisions. However, instances of preference divergence will highlight the need for broad public consultation schemes to be enacted. Cautioning that preferences may diverge due to varied knowledge bases, it may also suggest the need for more investment into public education and awareness campaigns.

This study has focused primarily on an area of high tourism pressure near Coral Bay in the centre of NMP. Further research is required along the remainder of the west coast where additional manta ray aggregations are known to occur.

Genetic analysis of geographically separate populations as well as the work done here will determine the need for state-wide protection of this species.

In addition there is a second highly migratory species of manta ray (oceanic manta rays) which visits NMP during the whale shark season. This larger species is known to be under considerable global fishing pressure yet we know even less about its migratory routes. Future research will target the prey preferences of this species within the Park and its migratory routes beyond.

Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/).

6.25 Project 3.9: Nursery ground and movement patterns for tropical rays at Ningaloo Reef, W.A.

Principle Investigator
Florencia Cerutti (Charles Darwin University/ AIMS/ CONACYT-México)

Research Team
Chris Austin (CDU), Mark Meekan (AIMS), Corey Bradshaw (U. of Adelaide)

Project Overview
Large benthic rays are important environmental modifiers, very common in tropical reefs, they constitute an important food source for developing countries and are an increasing tourist attraction all over the world. In spite of their environmental and economic importance, very little is known about the population and migration of tropical rays and their ecological importance. Although there is an increasing interest in the study and management of sharks' populations, the knowledge of batoids biology and ecology is still far behind. Rays and skates are targeted for fisheries throughout the world and are frequently taken as by-catch (White and Dharmadi, 2007, Dulvy et al., 2000). Rays have a life strategy that makes them extremely vulnerable to over fishing; it has been suggested that locally extinct populations may take decades to recover after over exploitation (Compagno, 1999, Field et al., 2009). Thus, the need of studies about biology and ecology has recently increased.

The role of environmental factors in the distribution and abundance of fish in the oceans is still poorly understood, however the relationship between environmental variations and the behavioral ecology of organisms is a key for ecological studies. Factors like temperature, salinity and depth have been proposed as important variables for determining such distributions (Wetherbee et al., 2007, Volger et al., 2008).

Understanding site fidelity, habitat use within a nursery area and the influence of environmental factors in their movements is important for determining spatiotemporal distribution and essential habitats for juvenile rays. Using passive acoustic monitoring, our study provides the first description of the movement patterns and site fidelity of rays within a coral reef environment in the lagoon of Mangrove Bay at Ningaloo Reef, WA. We focused on the use of nursery areas and contrasted movement patterns of juveniles with those of adults.

Objectives
We describe the first long-term (months to years) study of the movement patterns of rays within a coral reef environment in Western Australia. We used acoustic telemetry to monitor movement patterns and residency of tropical rays and focus on the identification and use of nursery areas by juveniles. We will also determine if there is any influence of temperature in the seasonality, movements and migration cycles of these species at Mangrove Bay. We contrast movement patterns of juveniles with those of adults.

Materials and Methods
We used the facilities of the Ningaloo Reef Ecosystem Tracking Array, which is part of the Australian Animal Tagging and Monitoring System (www.imos.org.au/aatams.html), a national network of acoustic receiver stations. Fifty-six receivers were deployed in Mangrove Bay and are downloaded every six months. Temperature loggers (VEMCO©, Halifax, Canada) were also attached to some receivers to register temperature at intervals of 30 minutes during much of the time of study.

We tagged rays in February and November 2008. We caught smaller rays (< 1 m disc diameter) with gill, throw or hand nets and landed on the shore. We sexed, measured (disc width and total length), externally tagged (spaghetti tag), and surgically fitted individuals with a VEMCO v13 (battery life of approximately 16 months) transmitter for passive monitoring. We externally tagged larger rays (> 1 m) with VEMCO v16 tags (battery life of approximately 42 months) while swimming in the wild. We fit tags with a stainless steel dart and wire and covered with anti-fouling paint; we inserted tags on the right side of the disc using a speargun.

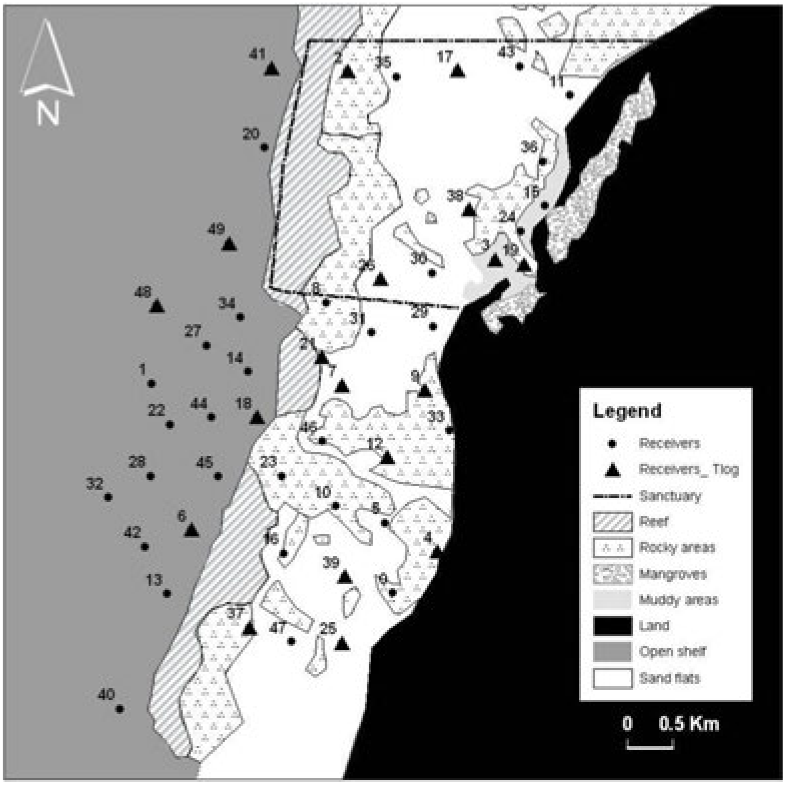

Figure . 1 A) locations of arrays of receivers along Ningaloo Reef, WA (1-Tantabiddi curtain, 2-Mangrove Bay array, 3- Point Cloates curtain, 4- Stanley's Pool array, 5-Point Maud curtain, 6-Skeleton Bay array). B) Mangrove Bay array of receivers, dashed line limits the area of Mangrove Bay sanctuary zone

The temperature through the study period and through the day was averaged and plotted with the monthly detections and diel detections of juvenile and adult rays. The minimum and maximum temperatures in the lagoon, outside of the reef and the primary sites was also averaged and plotted. We summed the number of detections in the array per month of the study for each individual to investigate seasonal movement patterns. The number of monthly detections was modelled as a function of month and species. Due to low numbers of adults sampled, adult data was excluded from the analysis. We then constructed a suite of linear mixed-effect models using all combinations of the explanatory variables where the random effect was the individual ray. The models were fitted in R using the R package nlme (Pinheiro et al., And the R Development Core Team . 2011). Models were compared and ranked according to Akaike's information criterion, corrected for small sample size (AIC_c), and by their relative goodness of fit, the AIC_c weight (Burnham and Anderson, 2002). We used the numbers of detections from each ray at each listening station to estimate site fidelity. We used the mean detection density (number of detections recorded at a receiver/number of days the receiver was in the water) to identify the receivers with the highest activity. For each individual, we identified both a 'primary' site (the receiver with the most detection records). We applied a spectral analysis (MATLAB, MathWorks, Natick, Massachusetts, USA) to identify monthly, weekly and hourly cycles in detections of juveniles and adults.

Key Findings

We provide the first evidence that juvenile rays are using the shallow and protected areas within the lagoon of a coral reef as nursery grounds.

Although all juveniles had detections throughout the array, 96% of detections occurred within the sanctuary zone. Three receivers located in the shallowest area of the array (> 2 m water depth) on muddy sediments and closest to the mangrove forests received 60% of the detections of both juvenile and adult rays of all species. We considered these receivers as primary sites.

Juveniles of P. atrus were detected within the area of the array from 5-18 months after tagging. Similarly, juveniles of U. asperrimus were detected for between 7-15 months, while juveniles of G. typus were recorded from 2-15 months after tagging. The upper time limit for detections of these species probably reflects the lifetime of the tag battery. Adults of G. typus were only detected in the array from 2-5 months after tagging. Adult females of G. typus that were tagged in February 2008 were not detected after March 2008, whereas a sub-adult male was detected until September 2008, after which time it visited an array 125 km to the south of Mangrove Bay.

The highest amount of detections of juveniles (May-Aug, 2008) coincides with the lowest temperatures of the year (Jul-Sep, 2008). Whereas adults show more detections during the warmer months.

While spectral analysis was unable to detect any weekly or monthly cycles, there were strong 12- and 24-hour cycles in detections of juvenile of P. atrus, G. typus, U. asperrimus and H. uarnak. Adult G. typus and T. lymma did not display any obvious cycles in detections. For all these species, around 80-90% of detections at night occurred at only one or two receivers, while detections during the day tended to be spread over more than two receivers. The lower temperature during the early morning was between 05.00 and 08.00 and the highest was between 15.00 and 18.00.

The receivers with more detections are in a shallow area that is strongly influenced by tidal cycles and we expected that rays would use the strong tidal flows in this area; however, the spectral analysis showed a cycle of detections every 12hrs, which is probably influenced more by temperature than by tides.

Management Implications

The presence of nurseries for rays at Mangrove Bay has important implications for management and conservation of these animals. We do not know what proportion of the population that this nursery serves, or from what spatial extent the habitat draws neonates and juveniles. Given the size of Ningaloo Reef (it stretches over more than 250 km of coastline) it is unlikely that it is the sole nursery, even though equivalent habitats with fringing mangroves are very rare along this coast. Our study clearly shows that some animals could be drawn to the nursery from distant regions of Ningaloo, given that animals we tagged were detected up to 150 km from the site of initial capture. For these reasons, it is fortunate that this habitat is protected within a sanctuary zone. Although a reasonable size to protect juveniles, our results suggest that this zone will not protect all elements of the population, particularly mature males, who tend to move over spatial scales far greater than the zone boundaries.

Acknowledgements

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Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/).

6.26 Project 3.9: DNA barcoding of rays at Ningaloo Reef.

Principle Investigator
Florencia Cerutti (CDU, AIMS, CONACYT-México)

Research Team
Chris Austin (CDU), Vivian Wei (CDU), Mark Meekan (AIMS), Corey Bradshaw (U. of Adelaide)

Project Overview
Taxonomic misidentification and the presence of cryptic species can seriously compromise the veracity of ecological studies, fisheries and conservation-related research and management. The challenges for ecologists seeking verifications of their field-based identification are not trivial. Even when adequate taxonomic keys and field guides are available it is often difficult to confidently identify species in the field, as ecologists may be dealing with juveniles, undocumented geographic variants, sexual dimorphism, and may need to examine microanatomy or take measurements of varying complexity. DNA barcoding potentially offers scientists who are not-expert taxonomists a powerful tool to support the efficiency and accuracy of field studies involving the identification of diverse and difficult taxa. The taxonomy of rays has received reasonable attention in Australia, though the fauna in remote locations such as Ningaloo Reef, WA, is relatively poorly studied and the identification of some species in the field is problematic. In this study we report an application of DNA-barcoding to the identification of tropical rays as part of ecological studies at Ningaloo Reef, and the issues encountered regarding its applicability.

Objectives
To confirm the field identification of rays from Ningaloo Reef by different researchers using CO1 sequences and investigate the potential of DNA Barcoding as an aid to species identification by comparing these sequences both amongst each other and with sequences deposited on the GenBank and BOLD databases.

Materials and Methods
Gill net, hand net, line and hook, Hawaiian sling with a modified tip, and Indigenous spear fishing were used to catch or obtain tissue sample of rays. Tissue samples were stored in DMSO in the field, then at -80ºC in the laboratory. Identification and disc with (DW) measurement were taken while handling each individual or prior to taking tissue samples in the case of free-swimming rays.

Two samples per species per site were collected for this study where possible. Samples from Northern Territory, Lizard Island (Queensland), and Halong Bay (Vietnam) were also used for comparative purposes. A specific focus was on the identification of tagged rays and any specimens of uncertain or unusual appearance. The samples were collected by different researchers and when possible a provisional identification was made in the field.

Figure 1. Sampling localities: Ningaloo Reef, Western Australia (1). Darwin harbor, Northern Territory (2), Lizard Island (GBR), Queensland (3), Vietnam (4).

Genomic DNA was extracted from muscle tissue using DNeasy Blood & Tissue Kit. The CO1 gene was amplified by polymerase chain reaction (PCR) using the primers FishF2 (5'TCGACTAATCATAAAGATATCGGCAC3') and FishR2 (5'ACTTCAGGGTGACCGAAGAATCAGAA3') designed by Ward *et al.,* (2008). PCR conditions and sequencing will be available in Cerutt-Pereyra, *in prep.*The sequence data was assembled using Mesquite 2.74. Identification of samples was revised after considering the results of two analyses. First, the sequences were submited once at a time in the BOLD Identification Engine (http://www.boldsystems.org) and GenBank nucleotide database (http://www.ncbi.nlm.nih.gov/nucleotide). Both engines matched each uploaded sequence with every other sequence present in their data bases and provided percentages of similarities with matching specimens (Table 2). In the second analysis, phylogenetic trees were constructed using ray sequences downloaded from both the GenBank nucleotide database and BOLD Identification Engine. Uncorrected pair-wise distances were generated in PAUP* 4.0b10 (Swofford, 2002). For this analysis, the name of the sequences used was updated. For initial species delineation, we grouped individuals that clustered together with similarity levels <3.5% of divergence which is the threshold recommended for CO1 of marine and it equates to approximately the 10x variation proposed by Herbert et al (2004). Multidimensional Scaling (MDS), implemented in SPSS, was used to further explore patterns of variation in groups displaying high levels of intra-speciation or geographic variation.

Key Findings

We present sequence data for 16 species belonging to 10 genera of rays. We barcoded 20 individual rays that were tagged as part of an ecological study at Ningaloo Reef, W.A., (Cerutti-Pereyra *et al in prep*) to confirm or correct the field identifications made by several researchers. For these samples, all identifications were verified with no misidentifications in the field

Sequences of *Himantura uarnak*, *H. fai, H. granulata, Aetobatus ocellatus*, *Pastinachus atrus, Dasyatis parvonigra, Taeniurops meyeni, Manta birostris, Taeniura lymma,* and *Urogymnus asperrimus* represent new sequences from Australia in relation to the GenBank nucleotide database. Data for *D. parvonigra, M. birostris,* and *P. atrus* represent new sequences from Australia in both BOLD and GenBank. Sequences for *Neotrygon ningaloonensis* have no matching sequences in either the GenBank or BOLD databases and new sequences of *N. kuhlii* from Vietnam are also presented

The sequences for the combined data set, grouped sequences into clearly defined operational taxonomic units, with two conspicuous exceptions: the *N. kuhlii* species complex and the *Aetobatus* species complex; the group with the most difficulties for field identification was the spotted whiptail rays referred to as the *'uarnak'* complex.

Of the 74 sequences tested only 19 sequences had consistent matches on both BOLD and GenBank (Table 3). As a consequence, there were a number of anomalies which meant that taxonomic identification of many species was not straight forward or consistent. These anomalies showed evidence of either cryptic species, misidentification of species associated with sequences on the databases, or misidentification of species in the field associated with this study.

Two sets of factors limited the successful application of DNA barcoding of rays at this time. The first set included: the presence of cryptic species; species complexes with unresolved taxonomic status; and species with intraspecific geographical variation. The second set included: the insufficient number of taxonomically verified entries in online data bases and the presence of lodged sequences inconsistent names. Nevertheless, the study did demonstrate the potential of the DNA Barcoding approach to confirm field identifications and discover species complexes with taxonomic issues.

Management Implications

DNA barcoding for fisheries management and ecological studies is a potentially valuable tool for confirming identification of elasmobranch species. The technique is especially useful when the whole animal can not be studied such as when shark fins are taken from fishermen who may be taking endangered species or individuals are being tagged. .

The usefulness of DNA barcoding as a tool for taxonomic identification is directly related to the quantity and quality of taxonomically verified sequences available on genetic data bases. In this regard, Australia and Indonesia are in a better position than other countries due the investment in elasmobranch DNA barcoding and taxonomic studies. Similar investment in the study of elasmobranch communities in other parts of the world are needed if DNA barcoding is to reach its full potential for this important group of marine species.

Acknowledgments

We thank the Australian Institute of Marine Science for financial support, and CONACYT-Mexico for an international grant to FC. We thanks P. Last for species identification. We thank A. Tan and D. McGaffin for tagging and sampling equipment manufacture. Also we thank F. McGregor, Mat Gray, Gavin Enver and the Anindilyakwa Rangers from Groote Eylandt. Many thanks to all the volunteers that were part of the field work for this project.

Data Resources

Metadata on this project is available at the WA Node of the Australian Ocean Data Network metadata catalogue (http://waodn.ivec.org.geonetwork/)

7 KNOWLEDGE TRANSFER AND UPTAKE (Project 3.6)

Translating science into management: development of a framework for knowledge transfer and uptake.

Dr Kelly Waples and Dr Chris Simpson, Marine Science Program, DEC

Science has a very important role to play in natural resource management through providing the information to guide and support management decisions, be they for direct operational actions, planning or the development of policy and legislation. Science is responsible for gathering the information to describe the natural environment (i.e. inventory and baseline knowledge) as well as developing understanding of natural and anthropogenic changes to the system and the implications of these changes over the long-term (i.e. process and prediction). This knowledge relates to providing a better understanding of the ecological and social assets of the system, the processes that sustain them and the potential impacts upon them. Natural resource managers then are responsible for developing strategies that will ensure the long-term protection and conservation of the natural resources taking into account social values and political imperatives along with the relevant science.

There is an obvious critical role for knowledge transfer between scientists and managers to ensure that management decisions are made with the best possible knowledge base. However, there is often a disjunct between the science community and decision-makers tasked with managing our natural resources. In recent years there has been a growing focus on developing the links between these two groups and ensuring that valuable science is recognised and incorporated into management planning and activities through knowledge transfer and uptake processes.

Institutions such as WAMSI enhance the capacity for this to happen through bringing together both management and research agencies into collaboratively planned and executed research programs. DEC, as one of the partners within WAMSI, has a vested interest in the application of science to conservation of biodiversity in WA. This is most evident through the research activities of Node 3 which is led by DEC. As outlined in the introduction to this report, the Node 3 Science Plan has a specific focus on research needed to improve and underpin the management of NMP. Further, it is critical to the success of this research program that the outcomes of the Node 3 research are acknowledged and incorporated into management planning and actions. Thus, one of the key roles of Node 3 has been to facilitate the interaction between management and science through the development of a framework that will foster and enhance knowledge transfer and uptake within DEC, resulting in better informed and improved management of NMP.

Knowledge transfer and uptake

Knowledge transfer and uptake refers to the process by which scientific understanding and relevant information is incorporated into management practices be it through planning, policy or operational activities. The flow of information has typically been considered a part of the adaptive management cycle which comprises planning, doing, evaluating, reporting and adjusting phases (Figure 1). Each revolution of the cycle should be premised on strong interaction between those gathering and assessing the information

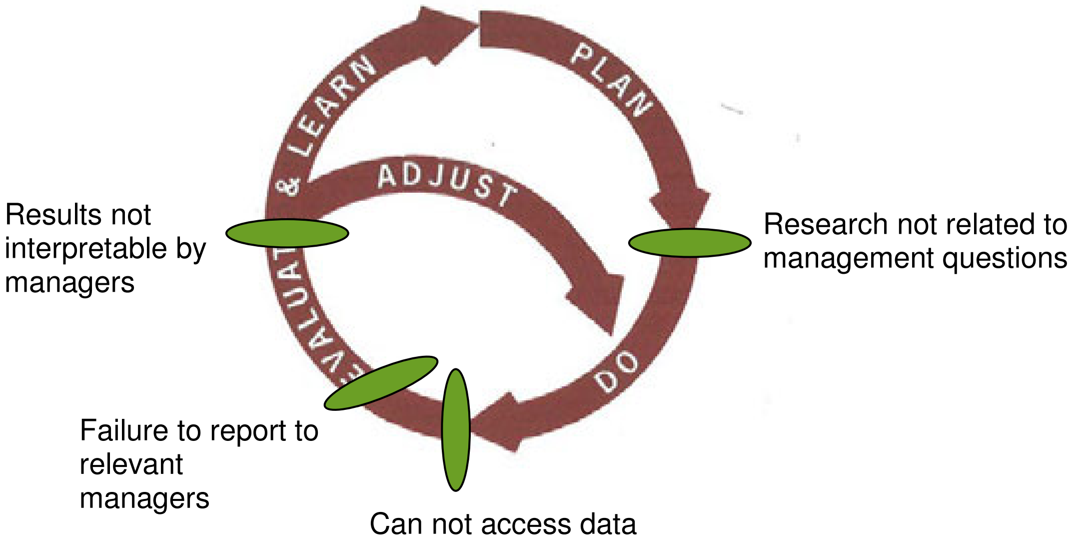

Figure 1. Depiction of the adaptive management cycle described by Jones (2005). Points highlighted in green signify barriers that crop up in this cycle, stalling the flow of information and inhibiting the application of science to management decisions and actions.

(researchers) and those seeking to use that information (managers/decision-makers). When there are political or social imperatives at stake this process can be quite seamless with managers seeking specific information to address a current hot issue and researchers responding in kind. However, with no such driver, the process can stall.

There is an extensive body of literature on the process of knowledge transfer, the adaptive management cycle and the various barriers that may block or derail it (e.g. Briggs 2006, Woodley 2006, Roux et al. 2006, Tomlinson and Davis 2010, McNie 2007, Burbidge et al 2011). To summarise, the main problems often stem from poor communication between managers and scientists based on differences in culture and work philosophy between the two groups (Roux et al. 2006). In general this can culminate in the two groups speaking a different language and not developing a shared understanding of the questions of interest or the application of the answers.

Further, the adaptive management cycle assumes there is a link between research providers and the individuals who would use that information in their daily activities or decision-making processes. However, this is not always the case. For example, in MPA management seven generic management strategies are typically employed in conservation activities (described in Table 1). Each type of strategy is typically within the work program of different individuals from different work areas across DEC. Administrative frameworks (park planning, zoning, regulations) are the realm of marine park planners and policy makers, education is the work of education officers, management intervention and compliance is the responsibility of marine park coordinators and rangers and research and monitoring are managed through the Marine Science Program. Scientists external to DEC are not often aware of the number and range of positions across DEC that may have a need and use for their information.

These factors result in a number of points within the adaptive management cycle where the process may become stalled or derailed (highlighted in Figure 1). We developed and trialled an operational framework that sought to develop a shared understanding and appreciation of the cultures, expertise and limitations of both scientists and managers, thus circumventing many of the limitations in knowledge transfer. In doing this we tried to bring an understanding of marine protected area management and information needs to scientists as well as an appreciation for the types of information and their generic applications to management strategies to managers.

Table 1 Steps in the knowledge transfer framework

1. Identify management needs and plan a strategic program of research
2. Develop management questions for projects based on the management needs outlined in (1) and discuss these with the relevant project leader
3. Construct a database containing research projects, objectives and potential application to management.
4. Use database to further discussions between end-users and researchers.
5. Collate final reports into an overall research synthesis highlighting science findings, applications and recommendations.
6. Finalise database focusing on ensuring long-term accessibility and distribute in conjunction with synthesis report
7. Guide/foster/assist with implementation of recommendations/actions as suitable

Knowledge Transfer Framework and Process

The following 7 step approach (Summarised in Table 2 and described in detail below) has been taken to ensure that knowledge uptake would be enhanced at the end of the research phase.

1. Identify management needs and create a strategic science plan

The first step to initiate an adaptive management process is identification of an issue or information need to direct or support management actions. In some cases this may be a specific and immediate issue (e.g. high mortality in turtle nest sites) or in other cases this may include previously identified information gaps with no immediate conservation consequence. It is typically the management agency that leads this step as they articulate the information needs or problems on which they look to science for support. In the case of MPAs in WA, management needs and information gaps have already been identified and prioritized in the individual MPA management plans.

The Node 3 science plan was based around the information gaps and priority research strategies identified in the NMP Management Plan (CALM 2005). The priority research areas were discussed with the science community to develop an agreed research plan that fit both the capability and interest in WA with the management information needs identified in the NMP Management Plan. Scientists were then asked to develop individual project proposals in their area of interest which were duly accepted into the Node 3 Science Plan.

2. Develop and distribute management questions

While the development of specific research proposals including project design and implementation is the responsibility of the scientists, managers should engage in this process by clearly articulating the questions for which they are seeking answers. By providing this information early on to scientists, it can be incorporated into project planning, study design and ongoing reporting, thus increasing the likelihood that research will be directed to topics of management interest and that the findings will reach those needing the information.

Careful consideration was given to each research project proposed under the Node 3 Science Plan including why it had been sought, the research strategy to which it related and, most importantly, what information MPA managers specifically needed to improve decision-making processes and actions. Each project typically generated 3-5 management questions which were discussed with the relevant project leader to ensure that they would be addressed through the research design and reporting schemes (Examples from 3 projects listed in Appendix 1).

3. Construct knowledge transfer matrix

Once research is underway, attention can now be directed to how this information will inform and direct management and the best means of ensuring it reaches the relevant end-users within an agency. An initial step is the development of an information matrix or database that contains a set of information on each project that will enhance the capacity for the research to be accessed by those with specific information and management needs. The database should include basic project details (title, project leader, objectives, expected outputs), research type (e.g. baseline, inventory, process prediction and social or ecological) as well as the management questions and management strategy to which it relates. In addition, the matrix should begin to identify potential application of the information through the seven generic categories of management for MPAs. Hill (2010) provides a detailed outline of the application of research type to the generic management strategies (summarized in Appendix 2).

A matrix of information was constructed for the research projects comprising the Node 3 Science Plan that included the fields identified above.

4. Expand the information matrix with input from scientists and end-users

The information matrix can now be used as a basis for discussion with both scientists and end-users to expand on the information it contains and to enhance the engagement between these two groups. Further, involvement with a broader range of end-users will ensure that the research is duly recognized and will increase the capacity to which individuals seek to apply the information in their working area. Discussions with these individuals can be used to more fully develop the implications of the various research projects, to clearly articulate specific management activities and to facilitate dialogue between scientists and specific end users.

User groups within DEC that have a role in MPA management, specifically that of NMP, were identified including individuals within Marine Policy and Planning Branch, Parks and Visitors Services, Marine Science Program and the Regional Exmouth District office. Staff within these various sections of DEC have responsibility for a range of marine management related roles including developing policies around MPA management, amending administrative frameworks, engaging in compliance and operational activities in the marine park, conducting research and monitoring activities and developing education programs relevant to specific target audiences. Separate meetings were held with each group to discuss the research program underway at NMP and to identify the specific information needs/interests and how the research might apply to operational or planning activities. In particular, we were keen to identify the most useful formats or means of getting the relevant science information across to each working group along with key issues on which the users sought information to guide policy and practice. This information was duly included in the knowledge transfer matrix and subsequently provided to project leaders so that they would have a better understanding of how their science might be applied, and by whom, as well as how best to present their findings in useful formats/products.

5. Collate Key Findings into a synthesis report and distribute

Once the research has been completed and final reports submitted, the Key Findings and their application can be interpreted and synthesized into a complete report that details the purpose of the research program, reviews cross cutting or broader issues, and provides key recommendations along with summaries of each individual research project and its implications for management. In addition, the report should list all communication outputs and sources of further information as well as the data resources and their availability.

Node 3 is addressing this issue through the publication of this final summary report. This report contains management focused, non-technical summaries of all Node 3 research along with a full list of projects and publications that have resulted from these projects. It highlights a number of the cross cutting issues that have been raised and put forward overall recommendations based on this multidisciplinary body of research. Finally, it identifies and lists a variety of information sources including publications, metadata databases and on-line information, produced over the last 5 years on NMP and its management. Similarly, the Cluster is producing its own final summary report. Ideally, these two elements will be brought together into a joint synthesis report which will stand as a repository for all the marine research conducted at NMP between 2005 and 2011.

It is hoped that this report alone will be a valuable resource to individuals with a role in marine biodiversity conservation or MPA management for NMP now and into the future as it is likely to be a decadal process over which the many recommendations are accepted and implemented. While all findings, outputs and relevant information cannot be contained within this one volume, the basic details are here and the direction to pursue further lines of enquiry where more detail is needed.

6. Finalise the information matrix for long-term accessibility and distribute

In addition to producing the synthesis report, the information from final reports and research summaries should be used to update and finalize the information database. This should include updating all implications for management and recording specific recommendations along with all research outputs (communication and data) and relevant formats. The database should include several searchable fields to aid in future use of the database such as 'key words' and 'research type' and should be ultimately made available to all end users, stakeholders and other interested parties.

The database for NMP research is being finalized and will be completed and distributed in conjunction with relevant information to assist users in identifying the most useful research projects to their needs (i.e. Appendix 3). It will also be made available through the internet via the WAMSI website, the Ningaloo Research website hosted by CSIRO and the Ningaloo Atlas, a web based tool designed and hosted by AIMS for promoting the uptake of science at NMP.

7. Guide/assist with the implementation of recommendations and actions

The last step in the framework involves the implementation of the recommendations and actions as identified. Through the development of the matrix a number of actions have been identified that need to be undertaken to ensure that end users have the appropriate type of information available to them as and when needed. There is a wide range of priority levels attributed to this list and the implementation process is expected to be a lengthy one with some actions occurring straight away, but many taking years to come to fruition. It must be recognized that natural resource management is a long-term activity and that actions will occur as resources become available and as they are required. The majority of the actions are related to the provision of data and information as appropriate materials and products for their use in management activities. The actions are generally captured in Appendix 3 which notes the types of outputs and products that are sought by end-users within DEC. While in many cases the available information provided through the final summary report or project reports is sufficient, in other cases, additional action may be needed to ensure that managers have information available to them in the format they need. This may be as simple as the construction of a specific GIS based map, the acquisition of a raw dataset for interrogation or the development of a mutually agreed policy document, management guideline or a planning guideline in which all parties have participated.

The culmination of WAMSI I and of Node 3 is the beginning point for this last step. There are early indications that there is a high interest in many of the proposed recommendations, but it will be a matter of time to see these implemented. This will be an ongoing activity for the Node 3 Leader and Science Coordinator to pursue and champion within DEC, where possible.

Critical overarching elements

Through developing this process and synthesizing the science from the NMP research it has become clear that there are several overarching elements required to enhance knowledge uptake over the longer term. These have all been addressed with the support of WAMSI, the Cluster and DEC. However, should one of these elements receive less attention, then the success of knowledge transfer process would be severely compromised likely resulting in blockages from the barriers typically experienced to applied science.

(1) **Data Management**. Long-term data storage and custodianship is critical to ensure that information is available and accessible into the future. Not only will this reduce the waste of additional resources going towards work that has been done, but it will also mean that data gathered today can be used to answer new questions in the future. This is becoming increasingly important in long-term monitoring programs and in exploring human related impacts such as climate change on natural systems. Further, managers with an operational role may have a need and use for many of the products that produced by research that is not immediately apparent. Access to these resources and the data behind them will enhance managers' abilities to respond to new needs and pressures at an operational level. This is particularly the case for GIS referenced datasets that can provide information on site specific biodiversity and features.

It is equally important to ensure that the information and outputs generated from research are functionally accessible, that is, available in a format or language that can be interpreted and used by managers and other non-scientists. Scientists are likely to quickly move on to new research projects, often in different geographical locations. Thus they will not be available over the long-term to continue to present or discuss their research findings. While there is always the expectation that all science is published in the peer-reviewed literature and thus permanently enshrined, this is not always the case. As pressure for scientists to move on to new funding sources increases, less time is made available for the actual publication of findings and outcomes other than through final reports which can be difficult to obtain.

In the case of NMP research, this has been addressed through the provision of metadata to an on-line database for all projects and through the storage of all data collected through WAMSI in a publicly available format. This report serves as a catalogue of the research undertaken and data products produced for future reference.

(2) **Communication** One of the largest impediments to knowledge transfer stems from poor communication between scientists and managers. It is critical that both groups are aware of the existence, working culture and philosophy of the other so that their respective work may achieve shared conservation goals. It is essential to ensure that there is a common understanding of marine resources, and their value, along with the questions that need to be answered to put in place the various measures that will ensure their conservation. It is equally important that this information is then imparted, in a palatable format, to those who are best placed to use it. Ideally this process should involve interaction between scientists and managers at several stages throughout the research-management cycle. This requires effort on both sides to ensure there are open lines of communication and regular opportunities for dialogue on issues of shared interest. In this regard the standard science communication avenues of research presentation through professional conferences and peer reviewed literature may miss the mark of a management audience that lacks the capacity both in terms of resources and technical capability, to access this information.

A great deal of effort was given to planning and executing communication through both Node 3 and the associated Cluster research program. A range of activities and media were used to maintain and enhance interaction within the science community as well as between scientists and relevant stakeholders (including agencies with management responsibilities and the general public). Some of the more important and useful initiatives included:

- Annual symposia held throughout the research program which afforded both scientists and managers the opportunity to share new findings and ideas and to appreciate the scope of research underway at NMP (NRCC 2007, 2008, 2009). In addition to the main research symposia, two student symposia were also held to bring together the many students engaged in research at NMP (NRCC 2009, 2010).
- Publication of a mid-program progress report (Waples and Hollander 2008) which described the scope and scale of research and provided early indication of how this information would be used to improve NMP.
- Synthesis workshop held in the final year of the research program to discuss key findings, implications for management and cross cutting issues between projects and disciplines. This event included both scientists and government agency decision-makers to broaden the scope of application of the research.
- Discussions, meetings and research presentations to stakeholder groups and the general public in Perth and Exmouth.
- On-line facilities such as research program websites (WAMSI and CSIRO Wealth from Oceans National Research Flagship) and the jointly managed Ningaloo Research Program website (www.ningaloo.org.au). The latter was used in particular to make available information and documents on the various research projects.
- Development of a series of project profiles which represented short, non-technical descriptions of each project along with key findings and their application to management, available on (www.ningaloo.org.au).
- Creation of the Ningaloo Atlas by AIMS as a further on-line resource for information, data and a means of visualizing the data. This resource will have a large application to management agencies as well as the general public.
- Initiation of a seminar series within MSP so that scientists can come and share their recent findings with the range of individuals interested in, and with a role in, the management of marine resources. These informal discussions are proving to be a very useful means of extending the dialogue between scientists and

managers and further developing communication for current and research initiatives.

We have collectively used these communication tools and activities to advance knowledge transfer and uptake and ensure that information moves between researchers and managers or users of that information not just in a single direction, but cyclically, enriching the perspective and working practices of all.

(3) **Intermediary/interpreter**. Even with the careful attention given to communication and data management, there is a recognized need for a means of bringing these elements together along with integrating the research and driving the knowledge transfer and uptake process. This includes a clear role in assisting with the interpretation of the science for its application to management action. Many natural resource managers do not have a background in science and do not necessarily have the capacity or ability to access and understand science reports and findings. Similarly, many scientists do not have a firm understanding of management agencies, their structure and their activities, thus limiting their ability to interpret their science into a useful format with realistic recommendations that will be noted and accepted by the relevant target audience(s). While the knowledge transfer framework presented here has been developed to assist with these limitations, the presence of an intermediary who has a shared role across science and management is integral to its success. This individual is best placed within a management agency yet with access to the science community through shared background, attendance at science symposia and other research initiatives.

A key position created within the Marine Science Program of DEC and appointed within Node 3 has been that of the Science Coordinator. This position has been dedicated to ensuring the smooth running of Node 3 science, communication and data management along with the integration of the science with that of the Cluster and other external research. This position has been instrumental in developing and implementing the knowledge transfer and uptake process specifically within DEC through liaison with the relevant scientists and DEC end-users. There is a recognized need for this role to continue beyond WAMSI and the Cluster to maintain contact with user groups to assist in prioritizing and implementing recommendations as appropriate. This latter phase should also include ongoing liaison with the research community through developing additional products from the research that will have management application (e.g. data products such as specific GIS referenced maps, publications on guidelines for management on specific issues).

Conclusion

We now have a much larger and stronger base upon which to build decisions for the management of NMP over the long-term. The commitment and support of both the science and management communities has led to the success of this framework for NMP along with the integral role of an agency based intermediary to help drive and guide the process. By recognizing the importance of each step in the process from knowledge generation to uptake and working together we hope that Node 3 will stand as a prime example of the value of science in marine natural resource management and the process will become embedded into DEC working practices.

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Knowledge transfer can only happen with the commitment and support of both managers and the science community. We would like to thank all of the Node 3 and Cluster scientists for their involvement in the process and their initiative in considering the management applications for their work. We would equally like to thank the DEC staff who engaged with this process through meetings, symposia and discussions. Finally, we'd like

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APPENDIX 1 Example management questions posed for four WAMSI Node 3 research projects.

3.1.1 Deepwater communities at Ningaloo Reef Andrew Heyward, AIMS	• What are the major benthic communities in deep water and how are they distributed? • Where are the areas of high biodiversity/hi primary productivity? • Do the sanctuary zones provide adequate and representative cover of these communities? • What is the abundance/biomass of the major species/functional groups • What is the significance of the biodiversity? • Are there environmental correlates of the distribution • Which functional groups/species can be used as indicators of community condition and what spatial and temporal scales should be used to monitor them?
3.2.2: Ecosystem impacts of human usage and the effectiveness of sanctuary zones in lagoon areas for protecting biodiversity Russ Babcock, CSIRO	• What is the diversity, abundance and size composition of key species in representative habitats inside and outside recently established sz? • How do historic unexploited and current exploited areas of NMP compare in relation to biodiversity, abundance and distribution? • Are current management arrangements/regulations (including the sz scheme) appropriate for preserving the biodiversity represented within the park? • What should management targets be for key species and ecological processes within the park? • Can we identify indicator species and a temporal/spatial scale for monitoring trends in biodiversity over time that will continue to demonstrate whether the sz plan is effective?
3.5.1 Oceanography of NMP Chari Pattiaratchi, UWA	• What are the pattern of water circulation and transport and the major 'drivers' of these patterns in NMP? • How does water movement influence the distribution of biodiversity (e.g connectivity, management units)? • Under what conditions and where in lagoons are current speeds a public safety hazard?
3.5.2 Biological oceanography of NMP-organism-scale nutrient dynamics Anya Waite, UWA	• What are the key elements in nutrient and energy flow across the Ningaloo Reef and how does this interact with broader oceanographic processes? • How does water movement influence the distribution of biodiversity (e.g connectivity, management units)? • What will be the implications should there be large scale changes to currents or oceanographic patterns?

APPENDIX 2 Generic MPA Management Implications based on research type

RESEARCH TYPE		GENERIC MPA MANAGEMENT IMPLICATIONS (NB how does the research outcomes contribute to these management activities?)						
		Management Frameworks	*Education*	*Surveillance & Enforcement*	*Management Intervention*	*Public Participation*	*Research*	*Monitoring*
		USERS MPA managers, planners, policy officers	**USERS** MPA managers, education officers	**USERS** MPA managers, compliance officers	**USERS** MPA managers, compliance officers	**USERS** MPA managers, planners	**USERS** Research scientists	**USERS** MPA scientists
Inventory (What is there?)	Socio-economic Values	Essential for development or review of management plan- detailing social values, conflicts, opportunities for consensus and zoning. Informs planning risk assessments. Identify human uses that require additional management (e.g. licensing, regulations etc). Informs planning of commercial activities. Estimation of socio-economic impacts and compensation where relevant. Informs development of statewide MPA system- location and boundaries for proposed MPAs (in respect to socio-economic values).	Will assist in the planning & development of public education programs (aspirations, behaviours, user profiles).	Will inform the design of compliance programs by identifying human use (risk, types, level & potential conflicts with mgmt rules). Will assist in the planning & development of education programs to minimise non-compliance.	Facilitates ongoing monitoring of risks and triggers for management change. Identify human uses that require additional management (i.e. controls, new facilities, education etc). to protect ecological values Provides information to develop community support for management restrictions. Informs licensing of commercial activities. Informs emergency response (e.g. oil spill).	Informs and aids planning and development of community consultation programs by identifying users and community based values of the MPA. Will assist the design of community-based social monitoring programs.	Assists in clarifying potential future research priorities/needs/gaps. Provides fundamental baseline knowledge to support the design and interpretation of future social research projects	Informs the development and design of social monitoring programs to establish baselines and measure changes in human use and values. Provides benchmarks for comparison with other MPAs. Will assist the design of community-based social monitoring programs.
	Ecological Values	Essential for development & review of management plans- detailing ecological values, risk assessments, special areas, & informs zoning. Informs development of statewide MPA system- location and boundaries for proposed MPAs to achieve CAR. Justification & community support for MPA establishment & planning activities.	Will provide important information for use in public education programs.	Will inform the design compliance programs by identifying areas of particular sensitivity/ecological value.	Clarifies biodiversity & conservation significance, level of importance and values & areas that require management intervention or additional protection. Informs assessment & design of new facilities & developments. Informs emergency response (e.g. oil spill). Provides information to develop community support for management restrictions. Inform the licensing of CTOs and researchers in relation to vulnerable and significant biodiversity/areas	Provides valuable information to support community consultation programs (i.e. why is the MPA important?) Will assist the design of community-based ecological monitoring programs.	Assists in clarifying potential future research priorities, needs & gaps. Provides fundamental baseline knowledge to support the design, implementation and interpretation of ecological research projects.	Identification of ecological values, KPIs (i.e. what is most important to monitor). Informs the development and design of monitoring programs to establish baselines and measure changes in ecological values. Will assist the design of community-based ecological monitoring programs. Provides benchmarks for comparison with other MPAs.

Project 3.6 Knowledge transfer and uptake

RESEARCH TYPE		Management Frameworks	Education	Surveillance & Enforcement	Management Intervention	Public Participation	Research	Monitoring
		GENERIC MPA MANAGEMENT IMPLICATIONS (NB how does the research outcomes contribute to these management activities?)						
		USERS MPA managers, planners, policy officers	**USERS** MPA managers, education officers	**USERS** MPA managers, compliance officers	**USERS** MPA managers, compliance officers	**USERS** MPA managers, planners	**USERS** Research scientists	**USERS** MPA scientists
Baseline (Quantifying the value, status, variability and trends)	Socio-economic Values	Informs planning risk assessments and development of management plans, zoning schemes through clarifying trends in human use (i.e. risks), and need for action to protect social values (e.g. indigenous heritage). Identification of management strategies to manage human uses (e.g. licensing, regulations etc). Assist licensing and management of commercial and recreational uses. Informs DEC/MPRA audit framework (pressures & trends).	Will assist the design of education programs by identifying changes in community aspirations and behaviours of MPA users. May assist in assessing the effectiveness of education programs (i.e. are users getting the message?)	Will inform the design compliance programs by identifying human use (types, level & potential conflicts with management rules). May assist in assessing the adequacy of compliance.	Will identify changes in human use over time that indicates need for management intervention to ensure sustainability (adaptive management). Will identify visitor infrastructure needs (e.g. upgrade of access points/relevant facilities).	Informs and aids planning and development of community consultation programs by identifying users, and changes over time of community based values and use of the MPA.	Provides fundamental baseline knowledge to support the design and interpretation of future social research projects Provides the knowledge base of the patterns and trends of human use. Assists in clarifying social research priorities, needs & gaps. Informs DEC/MPRA audit framework (pressures & trends).	Provides the foundation knowledge for the design of social monitoring programs (e.g. indicators, spatial and temporal scales, existing risks, emerging pressures etc). May contribute data of direct use in ongoing monitoring of social values. Informs DEC/MPRA audit framework (pressures & trends) Provides benchmarks for comparison with other MPAs.
	Ecological Values	Provides justification for MPAs-ecological values and status (i.e. need for special management). Essential for review of management plan-status of ecological values, informs risk assessments, management strategies, special areas, & management zoning. Identifies need for changes to regulations, licensing, and management arrangements for recreational and commercial uses. Informs DEC/MPRA audit framework. (status of ecological values & trends)	Will assist in the planning & development of public education programs and providing justification for restriction, controls & changes in users' behaviour. May assist in assessing the effectiveness of education programs (i.e. are users getting the message?)	Will inform the design of compliance programs by identifying ecological areas being impacted by use. May assist in assessing the adequacy and effectiveness of compliance programs.	Critical to identify need for management intervention to protect ecological values being degraded through human use. Provides information & justification to develop community support for management changes.	Will assist the development of community consultation programs.	Provides fundamental baseline knowledge to support the design and interpretation of future ecological research projects. Provides benchmarks for comparison with other MPAs. Assists in clarifying ecological research priorities, needs & gaps. Informs DEC/MPRA audit framework (pressures & trends).	Provide the foundation knowledge for the design of ecological monitoring programs (e.g. indicators, spatial and temporal scales, existing threats, emerging pressures etc). May contribute data of direct use in ongoing monitoring of ecological values. Provides benchmarks for comparison with other MPAs. Informs DEC/MPRA audit framework (pressures & trends)

Project 3.6 Knowledge transfer and uptake

RESEARCH TYPE		GENERIC MPA MANAGEMENT IMPLICATIONS (NB how does the research outcomes contribute to these management activities?) *Management Frameworks* USERS MPA managers, planners, policy officers	*Education* USERS MPA managers, education officers	*Surveillance & Enforcement* USERS MPA managers, compliance officers	*Management Intervention* USERS MPA managers, compliance officers	*Public Participation* USERS MPA managers, planners	*Research* USERS Research scientists	*Monitoring* USERS MPA scientists
Process (How does system function/cause /effects)	Socio-economic Values	Informs development of management strategies to maintain and enhance the socio-economic values. Informs development of management strategies, zoning etc. Informs development of statewide MPA system-location and boundaries for proposed MPAs to achieve CAR. Essential for review of management plans-how effective has management been?	Will assist the development of public education programs to increase community understanding of socio-economic values and how to maintain.	May provide information on the effectiveness of historical and current surveillance and enforcement programs.	Clarifies causes of impacts to socio-economic values-thus informing where management intervention is required. Will provide critical information for public discussion on the effectiveness of past and current management approaches.		Provides foundation baseline knowledge that clarifies understanding, on functions, relationships etc. Provides the foundation for targeted management related research. Assists in clarifying social research priorities, needs & gaps. Critical information to support effective modelling and prediction activities.	Informs design of social monitoring programs. (e.g. indicators, spatial and temporal scales, existing threats, emerging pressures etc). Critical to the interpretation of social monitoring results.
	Ecological Values	Informs Regional Marine Planning. Essential for development & review of management plans-detailing ecological values, risk assessments, special areas, & informs zoning. Facilitates more effective Ecosystem Based Management (e.g. integration with fisheries management). Informs planning risk assessments for management planning (i.e. cause-effect-pathways). Informs MPA design-reserve location (e.g. source/sink), boundaries, size and management zoning. Informs development of statewide MPA system-location and boundaries for proposed MPAs to achieve CAR.	Will assist the development of public education programs to increase community understanding.	Will inform the design compliance programs by identifying areas of particular sensitivity/ecological value.	Informs understanding of natural variability, and enables more effective decision making for management changes (e.g. 'impacts' may not be anthropogenic but caused through natural forces). Will provide critical information for public discussion on the effectiveness of past and current management approaches. Informs emergency response (e.g. oil spill).		Provides foundation baseline knowledge that clarifies understanding, provides the foundation for targeted management related research, and identifies new priorities/research needs. Critical information to support effective modelling and prediction activities.	Critical to the interpretation of ecological monitoring results (e.g. understanding natural variability to be able to isolate human induced changes from variation due to natural forces. Informs design of ecological monitoring programs (e.g. indicators, spatial and temporal scales, existing threats, emerging pressures etc).

Project 3.6 Knowledge transfer and uptake

RESEARCH TYPE		GENERIC MPA MANAGEMENT IMPLICATIONS (NB how does the research outcomes contribute to these management activities?)						
		Management Frameworks	*Education*	*Surveillance & Enforcement*	*Management Intervention*	*Public Participation*	*Research*	*Monitoring*
		USERS MPA managers, planners, policy officers	**USERS** MPA managers, education officers	**USERS** MPA managers, compliance officers	**USERS** MPA managers, compliance officers	**USERS** MPA managers, planners	**USERS** Research scientists	**USERS** MPA scientists
Prediction (Modelling/scenarios/ what ifs?)	Socio-economic Values	Informs Regional Marine Planning. Provides planning tools- modelling management options, meeting targets, community workshops models, scenarios etc) Inform assessment of socio-economic impacts development in or adjacent to MPAs (DEC/MPRA).	Tools and information to educate the community on MPA management options, scenarios, socio-economic impacts etc.	Assist in planning surveillance and enforcement requirements by predicting future changes in human use patterns, pressure points etc.	Assist in emergency response (e.g. oil spill, search and rescue etc). Informs understanding and decision making for management changes Assist the design and assessment of marine and coastal facilities.	Tools for encouraging public participation in management (e.g. workshops models, scenarios etc)	Supports other research by providing foundation understanding and predictive tools. Identifies areas where greater knowledge is required to improve the accuracy of socio-economic models.	Informs design of social monitoring programs. (e.g. indicators, spatial and temporal scales, existing threats, emerging pressures etc). Identifies monitoring data that is necessary to inform and improve accuracy of socio-economic models.
	Ecological Values	Informs Regional Marine Planning and long-term planning (e.g. climate change). Facilitates more effective Ecosystem Based Management (e.g. integration with fisheries management). Informs MPA design-reserve location, boundaries, size and management zoning. Assist the design of marine and coastal facilities. Informs EIA assessment of ecological impacts of development in or adjacent to MPAs.	Tools and information to educate the community on MPA management options, scenarios, impacts etc	Will assist the design of EIA compliance & monitoring programs (e.g. location of reference sites) by identifying areas vulnerable to potential climate change impacts (e.g. coral bleaching).	Will assist in emergency response (e.g. oil spill, search and rescue etc). Informs understanding and decision making for management changes. Assists the design and EIA of marine and coastal facilities.	Tools for encouraging public participation in management (e.g. workshops models, scenarios etc)	Identifies areas where greater knowledge is required to improve the accuracy of ecological models. Supports other research by providing foundation understanding and predictive tools (e.g. connectivity, nutrient and carbon flux etc.)	Identifies monitoring data that is necessary to inform and improve accuracy of ecological models. Informs design of ecological monitoring programs (e.g. indicators, spatial and temporal scales, existing threats, emerging pressures etc).

Project 3.6 Knowledge transfer and uptake

Appendix 3. Knowledge transfer framework identifying the research type for each Node 3 project and associated generic management strategies to which information gained can be applied. Bold red **X** signifies that the outputs are relevant to a management strategy from the NMP Management Plan, and should provide support or information to implement the strategy. Black "Xs" highlight where there are applications to other management areas. Specific details on application can be found in the research summaries and final reports. This table is a guide for users to identify which projects may have information that falls within their role to implement or take further. The format columns note the type of information and formats that some user groups in DEC (Region – Exmouth Region, MSP- Marine Science Program, MPPB – Marine Policy and Planning Branch) would find most useful and which will be sought as priority actions.

			Generic Strategies			Management				Format for Users		
Ref	**Project title**	**Type**	**Mgt**	**Edu**	**Sur**	**Int**	**PP**	**Res**	**Mon**	**Region**	**MSP**	**MPPB**
3.1.1	Deepwater biodiversity of NMP A Heyward (AIMS)	Baseline	**X**	X	X	X		X	X	Spatial dataset, maps, video/still footage, report summary	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on SZ suitability
	Deepwater habitat types of NMP A Heyward (AIMS)	Inventory	X	X	X	X		X	X	Spatial dataset, maps, video/still footage, report summary	Final reports, publications, spatial dataset	Spatial datasets, GIS layers, rec on SZ suitability
	Fish biodiversity and assemblages (deep water) E Harvey (UWA)	Baseline	X	X	X			X	X	Survey data, report summary	Final reports, publications, protocols	
	Species inventory database for NMP deep waters J Fromont (WAM)	Inventory	X	X	X	X		X	X	Spatial dataset, maps, species database, specimens for display	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on SZ suitability
3.1.2	Methods of monitoring the health of benthic communities M Depczynski (AIMS)	Baseline/ Process	X	X		X	X	X	**X**	Spatial dataset and map of important sites, photo library of juve fish, potential for community monitoring	Final reports, publications, protocols	
3.1.3	Stock assessment of target invertebrates of NMP-intertidal M Depczynski (AIMS)	Baseline	**X**	**X**	X			X	**X**	Spatial dataset and map of hot spots, photos and life history information	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on fishing reg adequacy
3.1.4	Local and regional migratory patterns of whale sharks at NMP M Meekan (AIMS)	Baseline	X	X			X	X	X	Summary report, map including high interaction areas, migration paths and distribution, monitoring	Final reports	Spatial datasets, GIS layers, rec on management of whale shark program

Ref	Project title	Type	Generic Strategies Mgt	Edu	Sur	Int	Management PP	Res	Mon	Format for Users Region	MSP	MPPB
										protocols		
3.2.1	Diversity, abundance and habitat utilization of sharks and rays J Stevens (CSIRO)	Baseline	X	X	X	X		X	X	Spatial dataset and map of habitats and distribution, species list, video and photos for education materials	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on adequacy of fishing regs and zoning
3.2.2	Ecosystem impacts of human usage and the effectiveness of sanctuary zones in lagoon areas for protecting biodiversity R Babcock (CSIRO)	Process	X	X	X	X		X	X	See projects below	See projects below	Recs on adequacy of fishing regs and zoning
3.2.2a	Broad scale fish surveys- shallow R Babcock (CSIRO)	Baseline	X	X	X		X	X	X	Spatial dataset and map of survey sites, survey dataset.	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on adequacy of fishing regs and zoning
3.2.2b	Intertidal invertebrate species B Black (UWA)	Inventory	X	X	X	X	X	X	X	Management guideline on intertidal species, species list, spatial dataset and map of vulnerable areas, photos for education material	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on adequacy of fishing regs and zoning
3.2.2c	Assessment of trophic cascade effects G Hyndes (ECU)	Process	X	X	X	X		X	X	Summary report with information on ecological process, Spatial dataset and map of primary production	Final reports, publications, protocols	rec on adequacy of fishing regs and zoning
3.2.2d	Lagoon invertebrates (crayfish) R Babcock (CSIRO)	Process	X	X	X	X	X	X	X	Spatial dataset and map of distribution and survey sites	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on adequacy of fishing regs and zoning
3.2.2e	Assessment of zone adequacy using fish tagging and tracking R Babcock (CSIRO)	Baseline	X	X	X	X	X	X	X	Spatial dataset and map of movement patterns, spawning	Final reports, publications, protocols	Spatial datasets, GIS layers, rec on

Project 3.6 Knowledge transfer and uptake

			Generic Strategies				Management			Format for Users		
Ref	Project title	Type	Mgt	Edu	Sur	Int	PP	Res	Mon	Region	MSP	MPPB
										sites, video/models of tracking for education material		adequacy of zoning and fishing regs
3.2.3	Management strategy evaluation- ElfSim R Little (CSIRO)	Prediction	X	X	X	X		X	X	Summary report	Final reports, scenarios and outputs	Recs on adequacy of fishing regs and zoning
3.2.3	ScenarioLab F Boschetti (CSIRO)	Prediction	X	X		X		X		Summary report	Summary report	Summary report
3.4.1	Reef morphology and growth history L Collins (Curtin)	Baseline	X	X		X		X	X	3D imagery of reef, GIS referenced map layers	Final reports, publications, spatial dataset	Spatial datasets, GIS layers
3.4.2	Characterisation of geomorphology and sedimentology and their links to habitat L. Collins (Curtin)	Baseline	X	X	X	X		X	X	GIS referenced map of bathymetry, geomorphology, sediments, seabed texture and habitats, management guideline on use of methods for habitat mapping and surrogacy	Final reports, publications, spatial dataset	Spatial datasets, GIS layers
3.5.1	Oceanography of NMP C Pattiaratchi (UWA)	Process	X			X		X	X	Model output and recs for public safety and oil spill management	Final reports, publications	Spatial datasets, GIS layers
3.5.2	Biological oceanography of NMP- organism-scale nutrient dynamics A Waite (UWA)	Process	X	X		X		X		Poster of process	Final reports, publications	Spatial datasets, GIS layers
3.8	NWMRI T Skewes (CSIRO)	Inventory	X	X				X	X	On-line searchable database		
3.9	Fish communities and habitats - lagoon to deepwater B Fitzpatrick (UWA)	Baseline	X	X	X	X	X	X	X	Thesis	Final reports, publications, protocols	Spatial datasets, GIS layers
3.9	The policy relevance of choice modelling A McCartney (UWA)	Baseline								Thesis	Final reports, publications	

Project 3.6 Knowledge transfer and uptake

			Generic Strategies				Management			Format for Users		
Ref	**Project title**	Type	Mgt	Edu	Sur	Int	PP	Res	Mon	Region	MSP	MPPB
3.9	Quantifying impacts of the Leeuwin current on the ecology and biogeochemistry of the Ningaloo reef C Rousseaux (UWA)	Process								Thesis	Final reports, publications	Spatial datasets, GIS layers
3.9	Hydrodynamic processes in the Ningaloo reef system S Taebi (UWA)	Process								Thesis	Final reports, publications	Spatial datasets, GIS layers
3.9	The role of microbial communities in reef building corals at NMP J Ceh (Murdoch)	Process								Thesis	Final reports, publications	
3.9	Ecology of manta rays F McGregor (Murdoch)	Baseline	X	X				x		Thesis, recs for management of tourism related activities	Final reports, publications	Spatial datasets, GIS layers
3.10	Assessment of coastal groundwater and linkages with Ningaloo Reef L Collins (Curtin)	Process	X			X		X	X	Spatial dataset and map of groundwater system and discharge points, report on linkages and water flow	Final reports, publications, spatial dataset	Spatial datasets, GIS layers, recs for research

8 Capacity building

Node 3 of WAMSI provided direct support to 9 post graduate students (8 PhD, 1 MS) and 3 post doctoral positions either through research grants or scholarships. An additional 23 students (4 undergraduate, 10 Hon, 2 MS, 7 PhD) have benefited from the Node 3 research either through their direct involvement and contribution to the research through their studies or through their use of the new information gained to further their research. Due to the increasing interest in marine research at NMP, available funding and supervisory opportunities, the number of students engaged in research at Ningaloo has expanded dramatically over the past 5 years. This has no doubt been enhanced by government investment and interest in research in this region and promotion by WAMSI and the Cluster of research effort and recognition. Two jointly hosted symposia specifically for students engaged in research at Ningaloo were held in 2009 and 2010. Both fora were well attended and resulted in discussion and linkages between projects across disciplines. All in all 70 students have either initiated or completed research projects at NMP to further their education between 2005 and 2011.

In addition to providing and supporting young scientists in WA, government investment in Node 3 has acted as a catalyst to prompt further investment in research in that region from National bodies such as CSIRO through the Wealth from Oceans National Research Flagship program, industry and many Australian Universities. This level of interest and research focus can be described through an assessment of the number of research permits issued leading up to and during the WAMSI period. Throughout the 1990's there was an average of 6 permits issued each year for research in NMP (minimum 4, maximum 11). This increased to an average of 15 during between 2000 and 2005 (minimum 10, maximum 19), but it wasn't until 2005 and later that the numbers began to really escalate with an average of 38 permits per year between 2005 to 2011 (minimum 29, maximum 52). This is a clear indication of the science effort stimulated by the initial interest and investment in WAMSI which was approved in 2005. Further, the research project database maintained by DEC on research at NMP now contains records of 149 projects that have been initiated or completed between 2005 and 2011 in comparison to the earliest draft of this database, developed in 2006, which recorded only 46 current projects.

9 Benefits

The Node 3 research program has delivered a range of benefits that will be realised by Government as well as the general community over years to come. These benefits range from the increased capacity for marine science in WA detailed above to specific tools, models and products of the research that can, and will, be used by government agencies in the management of our marine resources to the communication products developed to engage with the community and improve general understanding of our marine environment and what we need to do to conserve it. Overall these products will lead to improved sustainable management of marine environment. Specific benefits include:

- Increased research capacity and skill base in marine science for WA evidenced by the 18 post graduate, 10 Honours and 4 undergraduate students that were supported by or participated in the Node 3 research program;
- More than 40 peer reviewed publications and additional 40 reports produced by Node 3 scientists on their research, with more to come over the next 5 years;
- A voucher collection and draft guide to intertidal invertebrate species including photographs and information on siting locations and description
- A guide to juvenile fish species from the reef and lagoon system

- A hydrodynamic model of water circulation and flow across the reef and through the lagoon system;
- A management strategy evaluation model that assesses the effectiveness of management of fish species targeted by recreational fishers;
- A library of quality photographs and video of the variety of marine fauna and habitats in NMP including the spectacular sponge and filter feeder gardens of the deep water, fish and shark species including whale shark;
- GIS referenced map layers of the deep water benthic habitats and communities, bathymetry, groundwater system, sediments and geomorphological features
- Creation of the website facility the Ningaloo Atlas, as a repository for information and tool to access and view data on NMP
- Voucher collection held by WAM of 844 benthic invertebrate species,
- Detailed protocols, reference sites and baseline data to establish monitoring programs for coral and fish recruitment as well as the diversity and abundance of sharks, fish, lobster, intertidal invertebrates and deep water benthic invertebrates

Finally, focus of research and injection of funding into Ningaloo has stimulated further research effort that has complemented this research program and will continue to add to it far into the future. For example, Ningaloo has become a national site for the CERF reef surrogate program examining reef biodiversity as well as a reference site for Census of Marine Life – an international research program cataloguing marine biodiversity around the world. Ningaloo reef was also chosen as one of 3 sites in Australia for the Acoustic Telemetry and Marking System. This acoustic array was used in project 3.2.2 to improve our understanding of fish and shark movement patterns and habitat use. However the infrastructure will remain at Ningaloo and will be used for a range of projects examining biodiversity use of NMP.

10 Node 3 Outputs

10.1 Communication Outputs

Overall Node 3 has produced 60 publications, 32 reports (including an additional 46 milestone reports), 19 theses and 98 presentations to national and international conferences including published proceedings as well as an additional 58 presentations (i.e. seminars, meetings and public presentations. All outputs are listed below by project.

3.1.1 Deepwater biodiversity

Publications (1)

Heyward A, Fromont J, Schonberg CHL, Colquhoun J, Radford B, Gomez O. 2010. The sponge gardens of Ningaloo Reef, Western Australia. The Open Marine Biology Journal, 4:3-11

Reports (2)

Fromont J, Salotti M, Gomez O, Slack-Smith S, Whisson C, Marsh L, Sampey A, O'Hara T, Miskelly A, Naughton K. 2009. Identification of Demosponges, Echinoderms and Molluscs from the Ningaloo Deepwater Surveys – 2006 to 2008 Expeditions. WAMSI, Node 3, Project 3.1.1 Final Report. Submitted Aug 09. 29pp.

Heyward, A. 2008. Deep water biodiversity. Pages 16-19 in Discovering Ningaloo: latest findings and their implications for management. Ningaloo Research Program Progress Report. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, Perth WA.

Proceedings (9)

Colquoun, J. 2007. Deepwater communities at Ningaloo Marine Park. 84th Annual Symposium of the Australian Coral Reef Society, Esplanade Hotel, Fremantle.

Fitzpatrick, B, Harvey, Heyward, A. 2008. Lagoonal and cross-shelf patterns in the trophic structure of benthic fish assemblages on the Ningaloo Reef. In Proceedings of the Second Annual Ningaloo Research Symposium: Discovering Ningaloo- latest findings and their implications for management. 28 and 29 May, Murdoch University, WA. Ningaloo Research Coordinating Committee. Perth, WA.

Fromont J, Althaus F, McEnnulty FR, Williams A, Salotti M, Gomez O, Gowlett-Holmes K . 2010. Living on the edge: the sponge fauna of the continental margin and slope of Western Australia. 8th World Sponge conference 2010, Girona, Spain.

Fromont J, Radford B, Sampey A, Marsh H, Whisson G, Hosie, Heyward A. 2011. Deepwater biodiversity off Ningaloo Reef. Australian Marine Sciences Association 48th Annual Conference, Fremantle, WA.

Heyward, A. 2007. AIMS research at Ningaloo: an overview. First Ningaloo Research Symposium, Murdoch University, Perth.

Heyward, A. 2008. Ningaloo deeper water biodiversity surveys. In Proceedings of the Second Annual Ningaloo Research Symposium: Discovering Ningaloo- latest findings and their implications for management. 28 and 29 May, Murdoch University, WA. Ningaloo Research Coordinating Committee. Perth, WA.

Heyward, A. 2009. Ningaloo Deeper water biodiversity: a WAMSI collaboration in progress. In Proceedings of the Third Annual Ningaloo Research Symposium: Ningaloo into the future - integrating science into management. 26 and 27 May, Exmouth, WA. Ningaloo Research Coordinating Committee. Perth, WA.

Schönberg, C. 2010. Sponge gardens of Ningaloo Reef (Carnarvon Shelf, Western Australia) are biodiversity hotspots. 8th World Sponge conference 2010, Girona, Spain.

Schönberg, C. 2011. Australia's biodiversity hotspots: the sponge gardens at Ningaloo Reef, WA.. Australian Marine Sciences Association 48th Annual Conference, Fremantle, WA.

3.1.2 Monitoring the health of benthic communities

Publications (2)

Johansson CL, Bellwood DR, Depczynski M. 2010. Sea urchins, macroalgae and coral reef decline: a functional evaluation of an intact reef system, Ningaloo, Western Australia. Mar Ecol Progr Ser 414: 65-74

Wilson SK, Depczynski, M, Fisher, R, Holmes, T, O'Leary, R, Tinkler, P. 2010. Habitat associations of juvenile fish at Ningaloo Reef, Western Australia: the importance of coral and algae. PLoS ONE. 5(12): e151985. doi:10.1371/journal.pone.0015185.

Reports (1)

Depczynski M, Heyward A, McCase M, Colquhoun J, O'Leary R, Radford B, Wilson S, Holmes T. 2011. Methods of monitoring the health of benthic communities at Ningaloo- coral and fish recruitment. Final report submitted to WAMSI, Node 3. Perth, WA.

Proceedings (3)

Depczynski M, Wilson S, Holmes T, Tinkler P, Case M, Heyward A, Radford B . 2011. Juvenile fish assemblages of Ningaloo Reef. Proceedings of the 86th Annual Meeting of the Australian Coral Reef Society.

Depsczynski, M., Heyward, A, Radford, B, Babcock, R, Haywood, M. 2009. Current status of the invertebrate fauna targeted by fishers and the possible outcomes of different management alternatives. In Proceedings of the Third Annual Ningaloo Research Symposium: Ningaloo into the future - integrating science into management. 26 and 27 May, Exmouth, WA. Ningaloo Research Coordinating Committee. Perth, WA.

Wilson S, Depczynski M, Fisher R, Holmes T, O'Leary R, Tinkler P. 2010. Coral reefs and algal meadows as essential habitat for juvenile fish. 85th Annual meeting of the Australian Coral Reef Society, Coffs Harbour, NSW.

Other presentations (seminars, meetings, public presentations) **(3)**

Depczynski M, Heyward A, Birrell C, Colquoun J, Radford B, Wilson S, Holmes T. 2009. Coral and fish recruitment at Ningaloo. . AIMS/CSIRO Seminar, Floreat, WA.

Depczynski M, Heyward A, Colquoun J, Radford B, Wilson S, Holmes T. 2010. Coral and fish recruitment at Ningaloo. Public presentation, Exmouth, WA.

Depczynski, M. 2009. Project 3.1.2 - fish and coral recruitment. UWA seminar, Perth, WA.

3.1.3 Stock assessment- rock lobster and octopus

Publications (1)

Herwig J, Depczynski M, Roberts JD, Semmens JM, Gagliano M, Heyward AJ (in press) Using life history characteristics to investigate the lifecycle, biology and vulnerability of Octopus cyanea at Ningaloo Reef. Mar Ecol Progr Ser

Reports (1)

Depczynski, M, Heyward, A, Radford, B, O'Leary, R, Babcock, R, Haywood, M, Thomson, D. 2010. Stock assessment of targeted invertebrates at Ningaloo Reef. Final Report. Submitted June 2010.

Proceedings (2)

Depczynski, M., Heyward, A, Radford, B, Babcock, R, Haywood, M.. 2009. Current status of the invertebrate fauna targeted by fishers and the possible outcomes of different management alternatives. In Proceedings of the Third Annual Ningaloo Research Symposium: Ningaloo into the future - integrating science into management. 26 and 27 May, Exmouth, WA. Ningaloo Research Coordinating Committee. Perth, WA.

Herwig, J. 2010. Life history and ecology of *Octopus cyanea* Ningaloo Reef, Western Australia. Ningaloo Student Day, Floreat, WA.

Theses (1)

Herwig, J. 2010. Life history and ecology of Octopus cyanea at Ningaloo Reef, Western Australia. Hon. Thesis submitted to UWA.

Other presentations (seminars, meetings, public presentations) **(2)**

Depczynski, M. 2008. Current status of the invertebrate fauna targeted by fishers and the possible outcomes of different management alternatives.. AIMS/CSIRO Seminar, Perth.

Depczynski, M. 2010. The effect of ecology, life history and human pressure on marine fauna management. Public presentation, Exmouth.

3.1.4 Whale sharks

Publications (12)

Bradshaw CJA, Fitzpatrick BW, Steinberg CC, Brook BW, Meekan MG. 2008. Decline in whale shark size and abundance at Ningaloo Reef over the past decade: the world's largest fish is getting smaller. Biological Conservation 141: 1894-1905

Bradshaw CJA, Mollet HF, Meekan MG. 2007. Inferring population trends for the world's largest fish from mark-recapture estimates of survival. J Anim Ecol 76:480-489.

Castro, ALF, Stewart, BS, Wilson SG, Hueter RE, Meekan MG, Motta PJ, Bowen BW, Karl SA. Submitted. Population genetic structure of earth's largest fish, the whale shark (*Rhincodon typus*). Molecular Ecology 16:5183-5192

Sleeman, JC, Meekan, Bradshaw, CJA, Fitzpatrick, B, Steinberg, CC. 2009. Oceanographic and atmospheric phenomena influence the abundance of whale sharks at Ningaloo Reef, WA. Journal of Experimental Biology and Ecology 382: 77-81.

Sleeman, JC, Meekan, MG, Stewart, BS, Wilson, SG, Polovina, JJ, Stevens JD, Boggs, GS, Bradshaw, CJA. 2010. To go or not to go with the flow: environmental influences on whale shark migration patterns. Journal of Experimental Biology and Ecology 390: 84-98.

Sleeman, JC, Meekan, MG, Wilson, SG, Jenner, CKS, Jenner, MN, Boggs, GS, Steinberg, CC, Bradshaw, CJA. 2007. Biophysical correlates of relative abundances of marine megafauna at Ningaloo Reef, Western Australia. Marine and Freshwater Research, 58: 608-623

Speed CW, Meekan M, Bradshaw CJA. 2007. Spot the match - wildlife photoidentification using information theory. Frontiers in Zoology 4:2.

Speed, CW, Meekan M, Russell, B, Bradshaw, JA. 2008. Recent whale shark (Rhincodon typus) beach strandings in Australia. JMBA Biodiversity Records

Speed, CW, Meekan M, Russell, B, Bradshaw, JA. Submitted. First records of strandings of whale sharks (Rhincodon typus) in Australia. Bull. Mar. Sci.

Speed, SC, Meekan, M, Rowat, D, Pierce S, Marshall AD, Bradshaw CJA. 2008. Scarring patterns and relative mortality rates of Indian Ocean whale sharks. J Fish Biol 72: 1488-1503

Wilson SG, Polovina JJ, Stewart BS, Meekan MG. 2006. Movements of whale sharks (*Rhincodon typus*) tagged at Ningaloo Reef, Western Australia. Marine Biology. 148: 1157-1166

Wilson, SG, Stewart, BS, Polovina, JJ, Meekan, MG, Stevens, JD, Galuardi, B. 2007. Accuracy and precision of archival tag data: a multiple-tagging study conducted on a whale shark, Rhincodon typus, in the Indian Ocean. Fish Oceanog. 16:6, 547-554

Reports (1)

Meekan MG, Speed CW, Planes S, McLean C, Bradshaw CJA. 2008. Population monitoring for whale sharks (Rhincodon typus). Report prepared for the Western Australian Marine Science Institution and the Australian Government Department of the Environment, Water, Heritage and the Arts. Australian Institute of Marine Science, Townsville. 195 pp.

Proceedings (2)

Meekan, MG. 2007. Population biology of whalesharks at Ningaloo Reef. First Ningaloo Research Symposium, Murdoch University, Perth.

Meekan, MG, Bradshaw, CJA, Polovina, JJ, Wilson, S, Stevens, JD. 2008. Tagging and tracking the world's largest fish. In Proceedings of the Second Annual Ningaloo Research Symposium: Discovering Ningaloo- latest findings and their implications for management. 28 and 29 May, Murdoch University, WA. Ningaloo Research Coordinating Committee. Perth, WA.

Other presentations (seminars, meetings, public presentations) **(2)**

Meekan, MG. 2007. The ecology of whale sharks at Ningaloo: an overview. Biotracking Conference, Perth.

Meekan, MG. 2011. Whalesharks at Ningaloo. Public presentation, Exmouth.

3.2.1 Sharks and rays

Publications (1)

Last, P, White, WT, Puckridge, M. 2010. Neotrygon ningalooensis n. sp. (Myliobatoidei: Dasyatidae), a new maskray from Australia. Aqua International Journal of Ichthyology, 16:37-50.

Reports (2)

Speed, CW. 2008. Monitoring reef shark movement patterns with the Ningaloo Reef Ecosystem Tracking Array. Pages 20-21 in Discovering Ningaloo: latest findings and their implications for management. Ningaloo Research Program Progress Report. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, Perth WA.

Stevens, JD, Last PR, White, WT, McAuley, RB, Meekan, MG. 2010. Diversity, abundance and habitat utilisation of sharks and rays. WAMSI, Node 3, Project 3.2.1 Final Report. Submitted Jan 2010125pp.

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Speed, C. 2008. The Ningaloo Reef Ecosystem Tracking Array and reef shark movement patterns. In Proceedings of the Second Annual Ningaloo Research Symposium: Discovering Ningaloo-latest findings and their implications for management. 28 and 29 May, Murdoch University, WA. Ningaloo Research Coordinating Committee. Perth, WA.

Stevens J, McAuley R, Last P, White W, Chidlow J, Pillans R, Meekan M, Huveneers C, Speed C, McGregor F, Sugden M. 2008. Diversity, abundance and habitat utilisation of sharks and rays at Ningaloo Reef, WA. Meeting of the Oceania Chondrichthyan Society, Sydney, NSW.

Theses (2)

Cerrutti, F. in prep. Ecological and genetic connectivity of stingrays at Ningaloo Reef, WA.. PhD Thesis to be submitted to Charles Darwin university

Speed, C. 2011. Movement, behaviour and feeding ecology of reef sharks at Ningaloo Reef.. PhD Thesis submitted to Charles Darwin University

3.2.2 Effectiveness of zoning

Publications (5)

Black R, Johnson MA, Prince J, Brearley A, Bond T.2011. Evidence of large, local variations in recruitment and mortality in the small giant clam *Tridacna maxima* (Röding, 1798) at Ningaloo Marine Park, Western Australia. Marine and Freshwater Research 62(11):1318-1326.

Langlois TJ, Harvey ES, Fitzpatrick B, Meeuwig JJ, Shedrawi G, Watson DL. 2010. Cost-efficient sampling of fish assemblages: comparison of baited video stations and diver video transects. Aquatic Biology. 8:155-168

Verges A, Bennet S, Bellwood D. In review. Herbivore diversity on coral reefs: a transcontinental comparison. Submitted to Marine Ecology Progress Series

Verges A, Vanderklift MA, Doropoulos C, Hyndes, GA. 2011. Spatial patterns in herbivory on a coral reef are influenced by structural complexity by not by algal traits. PLoS ONE. 6:1-12. e17115.

Watson DL, Harvey ES, Fitzpatrick BM, Langlois TJ, Shedrawi G. 2010. Assessing reef fish assemblage structure: how do different stereo-video techniques compare? Marine Biology. 157: 1237-1250

Reports (9)

Babcock, R. 2008. Effectiveness of sanctuary zones for protecting subtidal fish communities. Pages 8-10 in Discovering Ningaloo: latest findings and their implications for management. Ningaloo Research Program Progress Report. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, Perth WA.

Babcock R, Vanderklift M, Clapin G, Kleczkowski M, Dennis D, Skewes T, Milton D, Murphy N, Pillans R, Limbourn A. 2008. Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation: broad-scale fish census. WAMSI, Node 3, Project 3.2.2 Final Report. Submitted Jan 2008. 100pp.

Babcock R, Vanderklift M, Murphy N, Clapin G, Limbourn A, Phillips J, Haywood M, Kozak D, Thomson D, McCleod I, Milton D, Skewes T, Dennis D. 2009. Lagoon Invertebrates. WAMSI, Node 3, Project 3.2.2 Final Report. Submitted Feb 2009. 40pp.

Babcock R, Vanderklift M, Murphy N, Clapin G, Limbourn A, Phillips J, Haywood M, Kozak D, Thomson D, Cook K, Davie H, Thomson, D, Downie R, Parker F, Bearham D. 2009. Trophic effects surveys. WAMSI, Node 3, Project 3.2.2c Final Report. Submitted Feb 2009. 55pp.

Black, B. 2008. Intertidal invertebrates of Ningaloo: a pilot study. Pages 14-16 in Discovering Ningaloo: latest findings and their implications for management. Ningaloo Research Program Progress Report. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, Perth WA.

Black, R, Brearley A, Johnson M, Prince J. 2011. Diversity, abundance and distribution of intertidal invertebrate species in the NMP. WAMSI, Node 3, Project 3.2.2b Final report submitted 2011. 452pp.

Fitzpatrick. 2008. Lagoonal and cross-shelf patterns in the trophic structure of demersal fish assemblages on the Ningaloo Reef. Pages11-13 in Discovering Ningaloo: latest findings and their implications for management. Ningaloo Research Program Progress Report. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, Perth WA.

Pillans R, Babcock R, Patterson T, How J, Hyndes G. 2010. Adequacy of zoning in the Ningaloo Marine Park. WAMSI, Node 3, Project 3.2.2e Final Report submitted to WAMSI. 87 pp.

Verges A, Hyndes G, Vanderklift M. 2011. Trophic effects through herbivory at Ningaloo Reef. WAMSI, Node 3, Project 3.2.2c Final Report submitted to WAMSI. 129pp.

Proceedings (22)

Babcock, R. 2007. Ecosystem effects of fishing at Ningaloo. 82nd Annual Symposium of the Australian Coral Reef Society, Esplanade Hotel, Fremantle.

Babcock, R. 2007. Ecosystems and fisheries effects of zoning. First Ningaloo Research Symposium, Murdoch University, Perth.

Babcock, R. 2009. Integrating science into management to support marine conservation: a management perspective. Pages 17-18 in Proceedings of the Third Annual Ningaloo Research Symposium: Ningaloo into the future - integrating science into management. 26 and 27 May, Exmouth, WA. Ningaloo Research Coordinating Committee. Perth, WA.

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Babcock R, Patterson, Bravington M, Pillans R. 2011. Including habitats in estimates of utilization distributions for reef fish. Australian Marine Sciences Association 48th Annual Conference, Fremantle, WA.

Black B, Johnson M, Brearley A, Kendrick A, Prince J. 2008. Intertidal invertebrates 2007 pilot study. In Proceedings of the Second Annual Ningaloo Research Symposium: Discovering Ningaloo- latest findings and their implications for management. 28 and 29 May, Murdoch University, WA. Ningaloo Research Coordinating Committee. Perth, WA.

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Fitzpatrick, B. 2005. Lagoonal and cross-shelf patterns in the distribution and biodiversity of benthic fishes on the Ningaloo Reef. AMSA Annual scientific conference, Adelaide.

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Michael P, Verges A, Hyndes G, Vanderklift M. 2011. Variation in macroalgae herbivory by fishes across a coral reef marine park. Australian Marine Sciences Association 48th Annual Conference, Fremantle, WA.

Michael, P. 2011. Variation in macroalgal herbivory by fishes across a coral-reef marine park. Australian Marine Sciences Association 48th Annual Conference, Fremantle, WA.

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3.2.3 ELFSim

Publications (5)

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Reports (3)

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3.4 Geomorphology

Publications (11)

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Reports (2)

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Theses (3)

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3.5.1 Hydrodynamics

Publications (5)

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Reports (1)

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Proceedings (14)

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Other presentations (seminars, meetings, public presentations) **(3)**

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Lowe, R. 2008. . Ocean Sciences meeting, Orlando Florida.

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3.5.2 Biological oceanography

Publications (5)

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Reports (2)

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Proceedings (10)

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Waite A, Wyatt A, Lowe R. 2009. The biological oceanography of Ningaloo Reef. 3rd Annual Ningaloo Research Symposium, Exmouth, WA.

Waite, A. 2007. Biological oceanography of Ningaloo Reef. 91st Annual Symposium of the Australian Coral Reef Society, Esplanade Hotel, Fremantle.

Waite, A. 2007. The biological oceanography of Ningaloo Reef. First Ningaloo Research Symposium, Murdoch University, Perth.

Wyatt, A. 2007. Trophic ecology of Ningaloo Reef WA, linking biogeochemistry and biodiversity. 92nd Annual Symposium of the Australian Coral Reef Society, Esplanade Hotel, Fremantle.

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Wyatt, A.S.J., Humphries, S., Waite, A.M., Lowe, R. and Babcock, R. 2008. Role of oceanographic processes in the trophic ecology of coral reefs: linking reef biodiversity and biogeochemistry. 11th International Coral Reef Symposium, Fort Lauderdale, Florida.

Theses (5)

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Other presentations (3)

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3.6 Knowledge transfer

Publications (10)

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Irvine, TR, Keesing JK (eds). 2007. The First International Whale Shark Conference: Promoting international collaboration in whale shark conservation, science and management. Conference Overview, abstracts and supplementary proceedings. . CSIRO Marine and Atmospheric Research, Australia. 98p

NRCC. 2007. Proceedings of the Ningaloo Marine Park Symposium, 16-17 July 2007, Murdoch University, Perth. Department of Environment and Conservation. Perth, WA

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Waples, K, Hollander, E. 2008. Ningaloo Research Progress Report: Discovering Ningaloo: latest findings and their implications for management. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, Perth WA.

Reports (5)

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Waples K, Simpson C. draft. Enhancing knowledge transfer and uptake: process for the Ningaloo Research Program. . Technical paper. Department of Environment and Conservation, Perth WA

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Simpson, C. 2007. A science based approach to the management of WA coral reefs: focus on Ningaloo Reef. 87th Annual Symposium of the Australian Coral Reef Society, Esplanade Hotel, Fremantle.

Simpson, C. 2007. Science for Management. First Ningaloo Research Symposium, Murdoch University, Perth.

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Steele, W. 2008. Ningaloo research website. 2nd Annual Ningaloo Research Symposium, Murdoch University, Perth.

Waples K, Simpson C. 2009. Integrating science into management to support marine conservation: a management perspective. Proceedings of the third Annual Ningaloo Research Symposium, Exmouth, WA.

Other presentations (seminars, meetings, public presentations) **(27)**

Mau, R. 2008. WAMSI Node 3 - Managing and conserving the marine state: best practice management and underpinning science. Ningaloo Sustainable Development Commission meeting, Coral Bay.

Simpson, C. 2008. Implementing the Marine Science Strategy and update on WAMSI Node 3. MPRA.

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Simpson, C. 2008. Node 3 annual report to the WAMSI Board. Presentation to the WAMSI Board, Perth WA.

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Simpson, C. 2010. Marine Science Program - Research and Monitoring. Presentation to the MPRA, Perth.

Simpson, C. 2010. Update on Node 3 Research. WAMSI Science Review, Perth.

Simpson, C. 2010. Ningaloo Research Program. WAMSI/AMSA Show and Tell , Maritime Museum, Perth.

Simpson, C and Waples, K. 2007. Research at Ningaloo Marine Park: best practice management and underpinning science. Coral Bay Society, Coral Bay.

Simpson, C and Waples, K. 2007. Research at Ningaloo Marine Park: best practice management and underpinning science. DEC and DoF staff, DEC, Exmouth.

Simpson, C and Waples, K. 2008. Research at Ningaloo Marine Park: best practice management and underpinning science. Exmouth Community, DEC, Exmouth.

Simpson, C and Waples, K. 2009. Node 3 Science Reviews- overall progress and projects 3.6, 3.7, 3.8. Science Review, Perth WA.

Waples, K. 2007. WAMSI Node 3 - Managing and conserving the marine state: best practice management and underpinning science. Tourism workshop, Curtin University, Perth.

Waples, K. 2007. WAMSI Node 3 - Managing and conserving the marine state: best practice management and underpinning science. CSIRO Wealth from Oceans Modelling Workshop, CSIRO, Melbourne.

Waples, K. 2008. The Ningaloo Research Program. DEC Pilbara Regional Meeting, Coral Bay.

Waples, K. 2008. Update on the Ningaloo Research Program. MPRA annual audit, Perth, WA.

Waples, K. 2008. WAMSI Node 3 - Managing and conserving the marine state: best practice management and underpinning science. WAMSI Show and Tell Science Day, Maritime Museum, Perth.

Waples, K. 2009. Knowledge Transfer in the Ningaloo Research Program. MPRA, Perth WA.

Waples, K. 2009. Update on the Ningaloo Research Program and its application to management. MPRA annual audit, Perth, WA.

Waples, K. 2009. Science to Action: development of a process for knowledge transfer and uptake with the Ningaloo Research Program. Nature Conservation Division annual conference, Perth WA.

Waples, K. 2009. Science to Action: development of a process for knowledge transfer and uptake with the Ningaloo Research Program. Parks and Visitors Services annual conference, Perth, WA.

Waples, K. 2009. Science to Action: development of a process for knowledge transfer and uptake with the Ningaloo Research Program. Science Division, Senior Management Team, Perth WA.

Waples, K. 2010. Science to Action: development of a process for knowledge transfer and uptake with the Ningaloo Research Program. DEC seminar series, Perth, WA.

Waples, K. 2010. Update on Ningaloo Research and application to management strategies. Presentation to the MPRA, Perth, WA.

Waples, K. 2010. Knowledge Transfer in the Ningaloo Research Program: from science to action. Ningaloo Research Synthesis and Integration Workshop, Floreat, NSW.

Waples, K. 2010. Research at Ningaloo Marine Park. Public presentation, Exmouth.

Waples, K. 2010. Update on project 3.6. WAMSI Science Review, Perth.

3.8 NWMRI

Reports (1)

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Other presentations (seminars, meetings, public presentations) **(2)**

Skewes, T. 2008. North West Marine Research Inventory: a tool for making marine data accessible. WA Marine Data Workshop, CSIRO, Kensington.

Vanderklift, M and Waples, K. 2007. North West Marine Research Inventory. WA Marine Data Workshop, CSIRO, Kensington.

3.10 Groundwater

Reports (1)

Collins LB, Stevens A. 2010. Assessment of coastal groundwater and linkages with Ningaloo Reef. . WAMSI, Node 3, Project 3.10 Final Report. Submitted Jan 10. 79pp.

Proceedings (2)

Stevens, A. 2005. Assessment of Groundwater impacts on the Ningaloo Reef System. Consortium for ocean Geosciences (COGS) of Australian Universities Conference, Curtin University, Perth.

Wilson, D. 2009. Assessment of coastal groundwater and linkages with Ningaloo Reef. In Proceedings of the Ningaloo Research Day for Students. 30 March 2009, Floreat WA.

Theses (1)

Wilson, D. 2008. GIS Analysis of Groundwater Occurrence in Ningaloo Marine Park, WA. Masters by coursework thesis. Department of spatial sciences, Curtin University.

Other presentations (seminars, meetings, public presentations) **(2)**

Stevens, A. 2005. Assessment of groundwater impacts on the Ningaloo Reef system. AMSA and WAMSI Show and Tell Science Day, Maritime Museum, Perth.

Stevens, A. 2008. Assessment of Groundwater impacts on the Ningaloo Reef System. Marine Science in WA show and tell .Newsflash, Maritime Museum, Perth.

3.9 Students (not covered in above projects)

Publications (2)

Parker, J. 2009. Taxonomy of foraminifera from Ningaloo Reef, Western Australia. Memoir 36 of the Association of Australasian Palaeontologists

Ceh, J, VanKeulen, M, Bourne, DG. 2010. Coral-associated bacterial communities on Ningaloo Reef, Western Australia. FEMS Microbiol Ecol1-11. doi: 10.1111/j.1574-6941.2010.00986.x

Reports (1)

McCartney, A. 2008. The policy relevance of choice modelling: an application to the Ningaloo and proposed South West Capes Marine Parks. Pages 81-83 in Discovering Ningaloo: latest findings and their implications for management. Ningaloo Research Program Progress Report. Ningaloo Research Coordinating Committee. Department of Environment and Conservation, Perth WA.

Proceedings (8)

Ceh, J. 2009. Coral associated microbes of Ningaloo Reef. In Proceedings of the Ningaloo Research Day for Students. 30 March 2009, Floreat WA.

McCartney, A. 2009. The policy relevance of choice modelling: an application to Ningaloo and Capes Marine Parks. In Proceedings of the Ningaloo Research Day for Students. 30 March 2009, Floreat WA.

McCartney, A. 2009. The Policy Relevance of Choice Modelling: An Application to the Ningaloo and Proposed Capes Marine Parks. In Proceedings of the Australian Agricultural and Resource Economics Society 53rd Annual Conference, Cairns.

McCartney, A. 2009. The policy relevance of choice modelling: an application to NMP. In Proceedings of the Third Annual Ningaloo Research Symposium, Murdoch University, Perth.

McGregor, F. 2010. Manta rays of Ningaloo reef. In Proceedings of the WAMSI Young Career Researcher Symposium, Joondalup, WA.

McGregor, F. 2011. Manta ray (*Manta alfredi*) visitation to Ningaloo Reef, WA - the importance of residence! In Proceedings of the Australian Marine Sciences Association 48th Annual Conference, Fremantle, WA.

Rogers, A. 2011. Is Choice Modelling Really Necessary? Public versus expert values for marine reserves in Western Australia, Melbourne. Australian Agricultural and Resource Economics Society 55th Annual Conference, Melbourne.

Wenziker, K. 2009. Ecology of Indo-Pacific humpback dolphins (*S. chinensis*) and bottlenose dolphins (*Tursiops sp*) in Ningaloo Marine Park. In Proceedings of the Ningaloo Research Day for Students. 30 March 2009, Floreat WA.

Theses (4)

McCartney, A. 2011. The policy relevance of choice modelling: an application to Ningaloo and Capes Marine Parks. PhD Thesis submitted to University of Western Australia

Ceh, J. In prep. Coral associated microbes of Ningaloo Reef. Phd Thesis to be submitted to Murdoch university

Johannson, C. in prep. Herbivory at Ningaloo Reef, WA. Phd Thesis to be submitted to James Cook University

McGregor, F. In prep. Trophic ecology of Manta Rays within lagoonal systems of the NMP. Phd Thesis to be submitted to Murdoch University.

Other presentations (seminars, meetings, public presentations) **(1)**

McCartney, A. 2009. The Policy Relevance of Choice Modelling: An Application to the Ningaloo and Proposed Capes Marine Parks. 2009 PhD Conference in Economics and Business, Perth.

10.2 On-line publications and information

WAMSI website - created and managed by WAMSI this website contains information on the Node 3 research program along with many useful documents including progress and final reports and symposia proceedings.

http://www.wamsi.org.au

Ningaloo Research Program website – a jointly created website by Node 3 and the Cluster that is hosted and management by CSIRO. It contains information on all research projects within these two research programs including project profiles that describe key research findings and their implications for management.

http://www.ningaloo.org.au/

Ningaloo Atlas website – developed and hosted by AIMS, this website provides a repository and viewing tools to view datasets and information about Ningaloo Reef and NMP collected through Node 3 as well as other research programs. It also contains a number of research summaries and an extensive library catalogue of published information on Ningaloo region.

http://dev.ningaloo-atlas.org.au

10.3 Data resources

Metadata for all research projects undertaken through Node 3 are available on-line via WA Node of the Australian Ocean Data Network (AODN) as noted in table 10.1.

http://waodn.ivec.org/geonetwork/srv/en/main.home

Data products, resources and their accessibility are detailed at the end of each project summary.

Table 10.1 Node 3 Metadata location on-line and main contact. To create a link to metadata record type http://waodn.ivec.org/geonetwork/srv/en/metadata.show?uuid=?????? Into your web browser with the relevant UUID as detailed in the table.   Entries in orange are held on the AIMS database and those in yellow in the CSIRO database.

UUID	Metadata title and project reference	Contact
e8866ab1-0cc0-4c4b-a215-033c4f38d717	WAMSI Node 3, Project 3.1.1(b) and 3.2.2 - Ecosystem Effects of Fishing: finescale coral reef fish surveys Ningaloo Reef	Ben Fitzpatrick (UWA)
e6dc4edd-fda9-4fe1-8ce7-1cfe514bcf6e	WAMSI Node3, Project 3.1.1(b) and 3.2.2 - Ecosystem Effects of Fishing: finescale coral reef fish surveys Ningaloo Reef - Mandu Sanctuary Zone	Ben Fitzpatrick (UWA)
634b6a24-c2b5-40ce-a058-ea7023bb7dc5	WAMSI Node 3, Project 3.1.1(b) and 3.2.2 - Ecosystem Effects of Fishing: finescale coral reef fish surveys Ningaloo Reef - Osprey Reference	Ben Fitzpatrick (UWA)
00fd279f-8c0e-465d-954c-0a8d173fc127	WAMSI Node 3, Project 3.1.1(b) and 3.2.2 - Ecosystem Effects of Fishing: finescale coral reef fish surveys Ningaloo Reef - Mandu reference	Ben Fitzpatrick (UWA)
95456119-7a31-4515-a488-cc432ecddb4b	WAMSI Node 3, Project 3.1.1(b) and 3.2.2 - Ecosystem Effects of Fishing: finescale coral reef fish surveys Ningaloo Reef - Osprey Sanctuary Zone	Ben Fitzpatrick (UWA)
1f70af70-3c03-11dd-b666-00008a07204e	WAMSI Node 3, Project 3.1.1 - Surveys of deepwater benthic communities using a benthic sled in NMP, Western Australia	Mark Case (AIMS)
e3af4340-3c05-11dd-b666-00008a07204e	WAMSI Node 3, Project 3.1.1 - Surveys of deepwater benthic communities using a Remote Operated Vehicle (ROV) in NMP, Western Australia	Mark Case (AIMS)
ef27ec8b-14c3-49ac-9096-0738a20d140d	WAMSI Node 3, Project 3.1.1 - Ningaloo hydro acoustic survey 2008 (Single Beam Sonar), Ningaloo Reef, Western Australia	Mark Case (AIMS)
3ee93980-377b-11dd-b786-00008a07204e	WAMSI Node 3, Project 3.1.1 - Single beam acoustic surveys in Ningaloo Marine Park, Western Australia	Mark Case (AIMS)
a112d920-3bfb-11dd-b666-00008a07204e	WAMSI Node 3, Project 3.1.1 - Surveys of deep water benthic communities using towed video in Ningaloo Marine Park, Western Australia	Mark Case (AIMS)
d395ccc1-8d4a-4236-9304-7a45961a9c77	WAMSI Node 3 Project 3.1.2 - Coral recruitment surveys, Ningaloo Reef, Western Australia	Mark Case (AIMS)
963d2acd-0a19-441c-bde1-4150e14b2e77	WAMSI Node 3 Project 3.1.2 - Juvenile fish recruitment surveys, Ningaloo Reef, Western Australia	Mark Case (AIMS)
53c6c3c5-e362-4bcd-9710-fefa2076fff9	WAMSI Node 3 Project 3.1.2 - Methods for monitoring the health of benthic communities, Ningaloo Reef, Western Australia	Mark Case (AIMS)
e8f43d2f-3417-42b1-a015-b7d4b1d68755	WAMSI Node 3 Project 3.1.3 - Crayfish and octopus surveys, Ningaloo Reef, Western Australia	Mark Case (AIMS)

963d2acd-0a19-441c-bde1-4150e14b2e77	WAMSI Node 3 Project 3.1.6 - Physical oceanography of NMP, Western Australia	Mark Case (AIMS)
7986fbdb-3239-4551-9f05-3b9bfdfe7fd5	WAMSI Node 3, Project 3.1.6 - Physical oceanography of NMP	Mark Case (AIMS)
	WAMSI Node 3, Project 3.2.1 - Diversity, abundance and habitat utilisation of sharks and rays - Summary	Hiski Kippo (CSIRO)
b5545d83-9413-426b-bf92-22958ac0a28f	WAMSI Node 3, Project 3.2.2 - Ecosystem Effects of fishing on Ningaloo Reef - Summary	Russ Babcock (CSIRO)
	WAMSI Node 3, Project 3.2.2 - Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation. Trophic effects through herbivory at Ningaloo	Adriana Vergés / Glenn Hyndes (ECU)
	WAMSI Node 3, Project 3.2.2a - Ecosystem Effects of fishing on Ningaloo Reef: Broadscale fish surveys	Russ Babcock (CSIRO)
516811d7-cca7-207a-e0440003ba8c79dd	WAMSI Node 3, Project 3.2.2b - Diversity, abundance and distribution of intertidal invertebrate species in the Ningaloo Marine Park	Bob Black (UWA)
080c6d0f-94ec-4cda-8442-b0b3f91fdfdd	WAMSI Node 3, Project 3.2.2c - Spatial variation in algal-herbivore interactions on the Ningaloo Reef, Western Australia	Adriana Vergés / Glenn Hyndes (ECU)
fcf07425-4517-4cd8-9618-670b0d77a8d6	WAMSI Node 3, Project 3.2.2c - Spatial variation in algal-herbivore interactions on the Ningaloo Reef, Western Australia: Regional differences in species-specific rates of fish herbivory on Sargassum in a reef-flat habitat	Peter Michael - (ECU)
	WAMSI Node 3, Project 3.2.2e - Ecosystem Effects of fishing on Ningaloo Reef: Acoustic tracking and adequacy of sanctuary zones	Russ Babcock (CSIRO)
	WAMSI Node 3, Project 3.2.3 - An Evaluation of Management Strategies for Line Fishing in the Ningaloo Marine Park	Rich Little (CSIRO)
244b0d15-97c8-4baf-baab-bccfceafcfb6	WAMSI Node 3, Project 3.4.1: Reef Morphology and Growth History – Eastern Ningaloo Reef (Exmouth Gulf) Development and demise of a fringing coral reef during Holocene environmental change, eastern Ningaloo Reef, Western Australia	Emily Twiggs (Curtin)
67984a64-c5bd-485d-8ace-7b0b22806ffa	WAMSI Node 3, Project 3.4.2 - Characterisation of Geomorphology and Sedimentology of Ningaloo Reef	Emily Twiggs (Curtin)
9f696497-0ba7-4415-be50-8c7a63f9564b	WAMSI Node 3, Project 3.5.2 - Biological oceanography - Reef organism isotopes	Alex Wyatt (UWA)
b8a1d3bd-c3dd-41e9-ad5b-006fa5867995	WAMSI Node 3, Project 3.5.2 - Biological oceanography - Water column biogeochemistry	Alex Wyatt (UWA)
516811d7-cc3a-207a-e0440003ba8c79dd	WAMSI Node 3, Project 3.5.1 - Characterisation and modelling of oceanographic processes in Ningaloo Reef and adjacent waters	Ryan Lowe (UWA)

e8866ab1-0cc0-4c4b-a215-033c4f38d717	WAMSI Node 3, Project 3.9.1 (see Project 3.2.2)	Ben Fitzpatrick (UWA)
67984a64-c5bd-485d-8ace-7b0b22806ffa	WAMSI Node 3, Project 3.9.2 (see Project 3.4)	Emily Twiggs (Curtin)
a9b2a271-cc09-4448-bc0c-f05ff1073c4f	WAMSI Node 3, Project - 3.9.3 - The policy relevance of Choice Modelling: an application to Ningaloo Marine Park	Abbie McCartney (UWA)
7d62f02a-b5df-41b9-bc56-2b7abd413289	WAMSI Node 3, Project - 3.9.4 - Quantifying impacts of the Leeuwin current on the ecology and biogeochemistry of the Ningaloo Reef	Cecile Rouseaux (UWA)
852dbfde-af31-4cde-808f-01801164a890	WAMSI Node 3, Project - 3.9.6 - The role of microbial communities in reef building corals along the Ningaloo Reef, WA	Janja Ceh (Murdoch)
f697576e-f081-4cf9-ab23-04ea8af974b2	WAMSI Node 3, Project p - 3.9.7 - Hydrodynamic processes in the Ningaloo reef system over a range of space and time scales	Soheila Taibi (UWA)
eef026c8-96e3-41fe-92a3-398d0282eb6f	WAMSI Node 3, Project - 3.9.8 - The trophic ecology and habitat requirements of the manta ray (Manta birostris) in lagoonal systems of Ningaloo Reef, WA	Frazer McGregor (Murdoch)
e88ef92e-7dd3-473a-b556-05c76519c32a	WAMSI Node 3, Project 3.10 - Assessment of Coastal Groundwater dynamics and linkages with the Ningaloo Reef	Alexandra Stevens (Curtin)

ACRONYMS

Acronym	Definition
AIMS	Australian Institute of Marine Science
ANU	Australian National University
AATAMS	Australian Animal Tagging and Monitoring System
BOM	Bureau of Meteorology
CDU	Charles Darwin University
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Curtin	Curtin University of Technology
DEC	Department of Environment and Conservation, WA
DoF	Department of Fisheries, WA
ECU	Edith Cowan University
GA	Geoscience Australia
IMOS	Integrated Marine Observation System
JCU	James Cook University
Murdoch	Murdoch University
SCU	Southern Cross University
STCRC	Sustainable Tourism CRC
UNE	University of New England
UNSW	University of New South Wales
UQ	University of Queensland
UWA	University of Western Australia
WAM	Western Australian Museum
WAMSI	Western Australian Marine Science Institution

Appendix 2 Database of all known research projects undertaken in Ningaloo Marine Park between 2005 and 2011.

Principle Researcher	Title	Institution	Objectives	Contact details for PI
WAMSI PROJECTS (organised by research theme and program structure)				
Project 3.1.1				
Heyward, Andrew	Deepwater biodiversity of Ningaloo Marine Park	AIMS	Assess the biodiversity value of the deeper waters seawards of the reef crest in NMP with a focus on representativeness of sanctuary zones.	a.heyward@aims.gov.au
Heyward, Andrew	Deep water habitat types of Ningaloo Marine Park	AIMS	Characterise the habitat types and dominant macro benthic communities in sanctuary zones and nearby comparison sites in waters between 20-100m depth	a.heyward@aims.gov.au
Harvey, Euan	Fish biodiversity associated with habitat types in the deeper waters of Ningaloo Marine Park	AIMS	Characterise the fish biodiversity associated with habitat types and dominant macro benthic communities in sanctuary zones and nearby comparison sites in waters between 20-100m depth	euanh@cyllene.uwa.edu.au
McCauley, Rob	High resolution data on cross shelf bathymetry and sediment facies	Curtin, AIMS	Improve the understanding of the biophysical domain via high resolution data on cross-shelf bathymetry and distribution of sediment facies	r.mccauley@curtin.edu.au
Fromont, Jane	Species inventory database for the deep waters of Ningaloo Marine Park	WAM AIMS	Collect voucher specimens to form the foundation of a species inventory database for deeper waters of NMP.	jane.fromont@museum.wa.gov.au
Project 3.1.2				
Depczynski, Martial	Methods for monitoring the health of benthic communities	AIMS	Design protocols and provide baseline data for a long term monitoring program for coral and fish communities in NMP addressing recruitment, and spatial and temporal replication	m.depczynski@aims.gov.au
Project 3.1.3				
Depczynski, Martial	Stock assessment of target intertidal invertebrates at Ningaloo Marine Park (octopus and rock lobster)	AIMS, UWA	Assess status of target species; characterise habitats associated with abundance and compare abundance in relation to human use	m.depczynski@aims.gov.au
Project 3.1.4				

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Meekan, Mark	Local and regional migratory patterns of whale sharks that visit Ningaloo Marine Park	CSIRO	Characterise whale shark abundance in and use of NMP in support of management strategies for the whale shark ecotourism industry.	m.meekan@aims.gov.au
Brinkman, Richard	Physical oceanography of the Ningaloo Marine Park: an enabling dataset to be used in oceanographic modelling	CSIRO	Provide an enabling dataset on dominant oceanographic processes in NMP on which further modelling exercises will be built	r.brinkman@aims.gov.au
Project 3.2				
Stevens, John	Diversity, abundance and habitat utilisation of sharks and rays in Ningaloo Marine Park	CSIRO, DoF	Characterise shark and ray diversity and abundance in the reserves and support development of management targets for them.	john.d.stevens@csiro.au
Babcock, Russ	Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity at Ningaloo Marine Park	CSIRO, UWA, ECU	Measure the distribution and abundance of organisms on the reef and assess their variation in the context of both previous and current zoning (size, age, configuration) and habitat in order to contribute to an assessment of the appropriateness of current management strategies for NMP	russ.babcock@csiro.au
Babcock, Russ	Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation: broad-scale fish census in Ningaloo Marine Park	CSIRO, UWA, ECU	Provide an assessment of indirect effects on fish community structure from fishing activities in NMP	russ.babcock@csiro.au
Black, Bob	The effectiveness of sanctuary zones in protecting intertidal invertebrate species in Ningaloo Marine Park	UWA	Describe species diversity, abundance, size and distribution in the intertidal zone of NMP taking into account habitat and fishing pressure. Compare current abundance and distribution with natural populations	rblack@cyllene.uwa.edu.au
Babcock, Russ	Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation: Trophic cascade surveys and experiments	CSIRO	Provide a robust quantitative assessment of whether evidence exists for direct (i.e. mortality due to fishing) and indirect (i.e. changes in interactions among species due to reduced abundance of fished species) ecological effects of fishing in NMP.	russ.babcock@csiro.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Verges, Adriana	Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation: algal-herbivore interactions at Ningaloo reef	CSIRO, ECU	Provide an assessment of indirect effects on benthic community structure from fishing activities in NMP	a.verges@ecu.edu.au
Babcock, Russ	Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation: lagoon invertebrates (rock lobster)	CSIRO	Provide robust quantitative assessment of the impact of fishing on lobster populations in NMP and whether there is evidence for the recovery of lobster populations in sanctuary zones.	russ.babcock@csiro.au
Babcock, Russ	Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation: assessment of zone adequacy using fish tagging and tracking	CSIRO	Gain a better understanding of movement patterns and habitat utilisation of key fish and elasmobranch species in NMP to assist in management decisions about zone size, distribution and adequacy.	russ.babcock@csiro.au
Little, Rich	An evaluation of management strategies for line fishing in Ningaloo Marine Park: ElfSim	CSIRO	Assess the impact of existing zonal management strategies on key target fish species and biodiversity using background data and knowledge currently held or being gathered	rich.little@csiro.au
Boschetti, Fabio	ScenarioLab- a desktop modelling tool for managers	CSIRO	Develop a modelling tool that can be used by managers/policy makers to consider the application of various management strategies in marine park management	Fabio.Boschetti@csiro.au
Project 3.4				
Collins, Lindsay	Reef morphology and growth history at Ningaloo Reef.	Curtin	Characterise the morphology and growth history of the reef system and identify growth characteristics relevant to maintenance of marine biodiversity and climate change impacts	L.Collins@curtin.edu.au
Collins, Lindsay	Characterisation of geomorphology and sedimentology and their links to habitats in Ningaloo Marine Park	Curtin	Characterise the coastal and seabed geomorphology of the reef system, including the deeper reserve areas offshore of the fringing reef Characterise the surficial sediments of the shallow (lagoonal) waters.	L.Collins@curtin.edu.au
Project 3.5				

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Pattiaratchi, Chari	Characterisation and modelling of oceanographic processes in Ningaloo Reef and adjacent waters	UWA	Develop the capacity to numerically simulate waves, currents, sediment transport and particle dispersion in a shallow complex reef environment over time and space scales	chari.pattiaratchi@uwa.edu.au
Waite, Anya	Biological oceanography of NMP- organism-scale nutrient dynamics	UWA	Assess the biophysical coupling in the vicinity of the reef through quantitative assessment of the particle size structure and chemical composition (including isotopic assessment) of the particulate organic matter in waters surrounding the reef. This will allow key biological processes important in determining the productivity and diversity of the reef to be linked at a basic level to the physical model (WAMSI 3.5.1).	waite@cwr.uwa.edu.au
Project 3.8				
Simpson, Chris	Northwest Marine Research Inventory (NWMRI)	DEC	Develop a meta database of marine and coastal research completed, current or proposed in WA (State and Commonwealth waters) form Kalbarri to the NT border in order to understand what scientific information currently exists for this region to facilitate a strategic and collaborative approach towards further marine research in Northern WA	Kelly.waples@dec.wa.gov.au
Project 3.10				
Collins, Lindsay	Assessment of coastal groundwater dynamics and linkages with Ningaloo Reef	Curtin	Characterise the hydrological and geological aquifer system of NMP including the coastal seawater/freshwater interface and pathways to the Ningaloo Reef lagoon Develop our understanding of the behaviour of the freshwater/seawater interface in relation to seasonal, tidal and episodic events	L.Collins@curtin.edu.au
Student projects				
Bevilaqua, Adelaide	The microhabitat associations of cowries (Cyprae spp.) within Ningaloo Marine Park	UWA	Assess the abundance and distribution of cowries in central part of rocky intertidal platforms at Ningaloo Marine Park.	rblack@cyllene.uwa.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Bond, Todd	Linkages between intertidal invertebrate assemblages and shore platform morphology in Ningaloo Marine Park, WA	UWA	Develop a typology of shore platforms within NMP from the investigation of morphological features measured onsite during visits and off-site using charts and maps to determine if shore platform morphology can help explain and predict intertidal invertebrate assemblages.	rblack@cyllene.uwa.edu.au
Cadee SA, Inman VL, McHarrie CG, Taylor JPA	Comparison of methods and intensity of sampling assemblages of species on intertidal platforms at Ningaloo Marine Park	UWA	Examine the effectiveness of three sampling methods for monitoring macroinvertebrate assemblages on intertidal rock platforms inside and outside Jurabi Sanctuary Zone, Ningaloo Marine Park.	rblack@cyllene.uwa.edu.au
Ceh, Janja	The role of microbial communities in reef building corals along the Ningaloo Reef	Murdoch	Investigate the dynamics of coral-associated microbial communities over a one year period in NMP.	j.ceh@murdoch.edu.au
Cerutti, Florencia	Ecological and genetic connectivity of rays at Ningaloo Reef, WA	CDU/AIMS	Determine the short (daily, weekly) and long (seasonal, yearly) term movements of benthic rays in lagoon systems along the reef, if tropical coastal rays show female philopatry and male-biased dispersion as the “large elasmobranch” hypothesis suggests; and the genetic flux and connectivity among and within populations at a variety of spatial scales.	florenciacp@gmail.com
Fitzpatrick, Ben	Lagoonal and cross shelf patterns in the trophic structure of demersal fish assemblages	UWA	Characterise the fish biodiversity and assemblages associated with habitat types and dominant macro benthic communities in sanctuary zones and nearby comparison sites in lagoon and deeper waters of NMP northern areas	russ.babcock@csiro.au
Herwig, Jade	Life history and ecology of Octopus cyanea at Ningaloo Reef, Western Australia.	UWA	Expand on previous research done on the ecology and life history of O. cyanea by using new ageing techniques to provide more accurate estimates. Examine the reproductive status and the density and distribution of individuals within these populations as well as possible trophic interactions.	m.depczynski@aims.gov.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Hinrichs, Saskia	Impacts of hydrodynamic shifts on coral condition at Ningaloo Reef	UWA	Determine how the condition of two dominant Acropora groups vary with current speed and how other environmental factors such as light, temperature nutrient availability impact coral condition	saskia-hinrichs@gmx.de
Loughridge, J	Do environmental variables explain differences in macroinvertebrate assemblages between intertidal rocky platforms: A case study conducted in the Northern section of Ningaloo Marine Park	UWA	Determine whether aspects of the nature of platform surface explains some of the variation seen in intertidal invertebrate assemblages at NMP.	rblack@cyllene.uwa.edu.au
McCartney, Abbie	The policy relevance of Choice Modelling: an application to Ningaloo and proposed Capes Marine Parks	UWA	Investigate the suitability of Choice Modelling as a tool for valuing marine parks and coral reefs using NMP as a case study. Investigate the differences between traditional and non-market valuation payment vehicles and tax reallocation using CM for an environmental good.	Abbie.rogers@uwa.edu.au
McGregor, Frazer	Trophic ecology of Manta Rays within the lagoonal systems of NMP	Murdoch	Investigate the trophic links between manta rays and NMP using mark recapture studies and assessing primary production.	frazer_mcgregor@yahoo.com.au
Michael, Peter	Regional differences in the piscine drivers of macroalgal herbivory in a coral-reef marine park	ECU	Qualitatively characterise species specific algal-herbivore interactions across reef habitats	PJMichael@skm.com.au
Parker, Justin	Foraminifera from Ningaloo Reef, Western Australia: Systematics and taxonomy	UWA	Identify and describe the foraminifera of NMP	
Rousseaux, Cecile	Production and transport of particulate matter in a regional current system	UWA	Quantify the mechanisms governing the amount of offshore primary production that crosses the continental shelf off NMP to contact the reef front, ultimately entering the Reef via wave-driven lagoon circulation	cecilerousseaux@gmail.com
Speed, Conrad	Monitoring reef shark movement patterns with the Ningaloo Reef Ecosystem Tracking Array	CDU	Determine long term patterns of habitat use and dispersal for reef sharks in NMP.	c.speed@aims.gov.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Taebi, Soheila	Hydrodynamic processes in the Ningaloo Reef System	UWA	Develop hydrodynamic models of circulation in lagoon areas of NMP	taebi@sese.uwa.edu.au
Tecchiato, Sira	Geomorphology, habitats and substrates of the shelf adjacent Ningaloo Reef	Curtin, University of Rome	Not Available	L.Collins@curtin.edu.au
Other WAMSI projects				
Feng, Ming	Impact of climate variability and climate change on coastal marine ecosystem	CSIRO	Quantify the climate variability in the Leeuwin Current physical forcings on the coastal ecosystem	Ming.feng@csiro.au
Ivey, Greg	Internal wave activity on the Australian North West Shelf	UWA	Improve the understanding of turbulent mixing in regions of internal wave generation, propagation and dissipation on the North West Shelf.	Greg.ivey@uwa.edu.au
NINGALOO COLLABORATION CLUSTER PROJECTS				
Project 1				
Lynch, Merv	Hyperspectral mapping - Bathymetry	Curtin	Use the hyperspectral data to create a bathymetry data set and broad scale classification of the lagoon habitats over the extent of the NMP Develop a radiation transfer model and optimisation code that can be used by researchers on a number of different systems to re-process atmospherically corrected reflectance data.	m.lynch@curtin.edu.au
Kobryn, Halina	Hyperspectral mapping - Habitats	Murdoch	Develop a high resolution characterisation of the reef and shallow water habitats of NMP that will provide the basis for future multiple use management and planning	h.kobryn@murdoch.edu.au
van Keulen, Mike	Habitats and Biodiversity of Ningaloo Reef lagoon	Murdoch, Curtin, UQ	Provide comprehensive information on habitats and biodiversity in NMP, particularly for macroalgae Identify hot spots and develop an understanding of the	keulen@murdoch.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
			environmental and habitat factors that explain the distribution of these hotspots	
Project 2				
Beckley, Lynnath	High resolution mapping of reef utilisation by humans at Ningaloo Marine Park	Murdoch	Determine spatial and temporal distribution of recreational activities along the shore and within the reef lagoon system of NMP Investigate the spatial distribution of recreational use in NMP in relation to biodiversity, habitats, physical conditions, park zoning, access roads and tracks and accommodation nodes Describe the demographics, frequency of visitation, choice of destination, socioeconomics, and catches of rec fishers Develop an understanding of historical use patterns at NMP from other potential sources of data on reef utilisation	l.beckley@murdoch.edu.au
Project 3				
Wood, David	Social and economic assessment of tourism along the Ningaloo Coast: a dynamic modelling approach (Socio-economics of tourism)	STCRC, Curtin, ECU, Murdoch	Develop a dynamic model of NMP incorporating social, economic and environmental management assessment of tourism along the Ningaloo coast Assess the social-economic implications of tourism to the Ningaloo coast Use the model to investigate the impacts of different tourism and development scenarios on the economy, communities and environments of NMP and its surrounding regions	d.wood@curtin.edu.au
Jones, Tod	Ningaloo destination model for scenario evaluation and collaborative planning	Curtin	Develop a dynamic model of NMP incorporating social, economic and environmental management assessment of tourism along the Ningaloo coast	T.jones@curtin.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Wood, David	Continuation of long term survey of visitation	Curtin	Not Available	d.wood@curtin.edu.au
Project 4				
Burton, Michael	Estimation and integration of socioeconomic values of human use of Ningaloo: models for recreational fishing and non-recreational fishing choices	UWA, ANU	Develop an empirical model to explain choice of recreational sites and use as a basis for economic welfare and policy evaluation for NMP.	Atakelty.hailu@uwa.edu.au
Project 5				
De la Mare, Bill	Management Strategy Evaluation (MSE) for the Ningaloo Region	CSIRO	Develop and provide the integrated modelling and analysis for Multiple use MSE of the Ningaloo region, drawing upon the outputs of the other Cluster and WAMSI projects and provide additional outputs in relation to ecosystem modelling, integrate the work of the Cluster and WAMSI and provide outreach capacity to stakeholders.	Bill.delamare@csiro.au
Dambacher, Jeff	Qualitative modelling for sustainable tourism development	CSIRO	Develop alternative constructs of socio-economic and ecological system modelling based on patterns, processes and responses determined from Cluster and WAMSI projects; explore the consequences of model structure and system dynamics; and facilitate stakeholder involvement in the process	Jeffrey.dambacher@csiro.au
Fulton, Beth	Integrated software for multiple use management strategy evaluation	CSIRO	Develop a regional management model for Ningaloo Region using a variety of factors including biophysical, social, assessment, monitoring and management policy for multiple use management strategy evaluation	Beth.fulton@csiro.au
Syme, Geoff	NREP Client outreach	CSIRO	Integrate the WAMSI and Cluster research and ensure implementation of outcomes through relevant stakeholders	g.syme@ecu.edu.au
Student Projects				

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Chapman, Kelly	Research uptake in Ningaloo: Barriers and Opportunities	ECU	Explore institutional capacity to respond and adapt to feedback from research and modelling work being done in the Ningaloo region Bring together researchers, policy makers, resource managers and resource users in a bid to identify and overcome barriers to establishing adaptive institutional arrangements in the Ningaloo region.	kelly.chapman@gmail.com
D'Andrea, Luisa	Using hyperspectral imagery to map vegetation condition and ground cover of the coastal area at Coral Bay	Murdoch	Assess the hyperspectral imagery of the coastal strip around Coral Bay to interpret vegetation condition, distribution and substrate type	h.kobryn@murdoch.edu.au
Neiman, Jodie	Diurnal variability in beach use patterns at Bundegi, Turquoise Bay and Coral Bay, Ningaloo Marine Park	Murdoch, DEC	Determine the diurnal pattern of human usage at Bundegi, Turquoise Bay and the main beach at Coral Bay by addressing the diurnal variation in beach use and can an understanding of beach use patterns facilitate an improved approach to beach management	l.beckley@murdoch.edu.au
Smallwood, Claire	Spatial patterns of human usage in the Ningaloo Marine Park	Murdoch	Quantify human use patterns of NMP in space and time.	c.smallwood@murdoch.edu.au
ADDITIONAL PROJECTS IN NMP (Arranged alphabetically by principle researcher)				
Armstrong, Shannon	Bills Bay Coral Recovery Research and Monitoring Project	DEC	Determine the recovery of corals in Bills Bay after the 1989 anoxic coral spawning event	kim.friedman@dec.wa.gov.au
Armstrong, Shannon	Long term monitoring of NMP: Status of Drupella and shallow water benthic reef communities.	DEC	Determine changes to Drupella density and percentage cover of coral communities at NMP over time	kim.friedman@dec.wa.gov.au
Beaton Rowena	Biogeochemistry of Ningaloo reef.	UWA	Not Available	
Bejder, L	North west cape, Exmouth: a hotspot for Indo-pacific humpback dolphins (Sousa chinensis) in WA	Murdoch	Assess abundance and distribution of humpback dolphins in NMP and Exmouth gulf and their connectivity with coastal populations across north-western Australia.	l.bejder@murdoch.edu.au
Berger, Yuval	Cycles of vertical habitat use in whale sharks (Rhincodon typus) tagged at Ningaloo	UNE, AIMS	Collect data on diel movements of whale sharks in the water column using Time Depth Recorders (TDRs) to look for	yuvalber7@gmail.com

Principle Researcher	Title	Institution	Objectives	Contact details for PI
			patterns in vertical habitat use.	
Brooke, Brendon	Testing surrogacy relationships-survey of the Carnarvon Shelf	GA, AIMS, CERF Biodiversity Hub	Gather multibeam, video and sediment data on major benthic habitat types across the Carnarvon shelf to test the utility of several physical variables as surrogates for patterns of benthic biodiversity. This dataset will complement that of the WAMSI deepwater biodiversity study.	NA
Bunning, Jessica	Spatial quantification of the impacts of off-road vehicles (ORVS) along the remote Ningaloo coastline of Western Australia	Murdoch	Quantify the relationship between potential turtle nesting sites and beach accessibility and evaluate the degree of human interference at different turtle nesting beaches based on beach accessibility to humans.	h.kobryn@murdoch.edu.au
Caley, Julian	Creefs Project of the Census of marine life	AIMS	Ningaloo Reef will serve as one reference site in the global project censusing marine life.	j.caley@aims.gov.au
Cassata, L	Coral reef communities, habitats and substrates I and near sanctuary zones of Ningaloo Marine Park	Curtin	Map and describe benthic habitats, substrates and reef communities in NMP and examine correlations between reef morphology, substrates, coral communities relative to energy gradient in water circulation.	L.Collins@curtin.edu.au
Catlin, James	Sustainability of the whale shark tourism industry at Ningaloo	Curtin	Assess socio economic impacts of the changes, over time, to the types of wildlife tourists that participate in whale shark tourism at NMP.	james.catlin@gmail.com
Ceccarrelli, D	Impacts of Commercial Shipping on Ningaloo Marine Park (Commonwealth Waters)	Uniquest (UQ)	Review and assess the impacts of commercial shipping on the key values in the Commonwealth waters of NMP.	NA
Chalmers Aisha	Temporal and spatial variability in coral condition at Sandy Bay, NMP	UWA	Not Available	Anya.waite@uwa.edu.au
Chandler, Philippa	Reef Encounters: how repeat visitors to the Ningaloo region may be impacted by tourist management changes	Curtin	Determine how changes to management of NMP as a tourist destination will impact upon repeat-visitors and their relationships with its physical and cultural environments by exploring the experiences and attitudes of people who regularly holiday at NMP and evaluating the potential influence of repeat visitors attitudes and values on future tourism planning in the region	pippagirl@hotmail.com
Collins, Lindsay	Climate change and coastal zone management of Carnarvon and Ningaloo Coast	Curtin	Not Available	L.Collins@curtin.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Collins, Lindsay	Geological history of Cape Range and Ningaloo Marine Park. (Geological evolution of Ningaloo Reef. Evolution and climate history of the Limestone of the Cape Range)	Curtin	Collection of rock samples for study into geological evolution, marine processed, reef growth history and land management of the Cape Range region	L.Collins@curtin.edu.au
Collins, Lindsay	Ningaloo Coastal Management Project	Curtin	Not Available	L.Collins@curtin.edu.au
Dutton, Andrea	Timing and magnitude of sea level change during the Last Interglacial (~125,000 years ago)	ANU	Date the timing of reef growth during the last interglacial in the Ningaloo/Cape Range region to better understand the degree of stability of sea level during an interglacial climate, such as the one we are presently experiencing.	andrea.dutton@anu.edu.au
Foster, Taryn	Ecophysiology of Pocillopora damicornis at Ningaloo Reef and response to higher oceanic temperatures due to climate change	Murdoch	Assess natural variability in photosynthetic performance of reef building coral within on e colony and between colonies Assess the resilience of P. domicornis from WA tropical waters, to higher sea surface temperatures predicted due to climate change, in an aquarium setting	keulen@murdoch.edu.au
Fowles, Brooke	A history of fish and fishing in Ningaloo	UWA, DEC	Analyse the historical prevalence of specific finfish within the bioregion with reference to oral history interviews and other historical sources, and evaluate the utility of this methodology.	
Fromont, Jane	The significance of historical collections: Ningaloo	WAM	Database the common marine invertebrates from NMP as indicated from historical collections dating back to the 1960s	jane.fromont@museum.wa.gov.au
Fulton, Chris	The effect of wave energy on algal growth	ANU	Understand the temporal (Seasonal) changes in algal community structure and determine methods to measure algal community patch size with remote sensing.	christopher.fulton@anu.edu.au
Gagliano, M	Baseline variability of pH on Australian coral reefs: comparing Ningaloo Reef and the Great Barrier Reef	UWA	Describe the levels of spatial variability in pH by comparing samples from the east and west coast of Australia and from reef microhabits within a reef system	monica.gagliano@uwa.edu.au
Gazzani, Flavio	Economic valuation of biodiversity conservation. Citizen's non-use value for Ningaloo Reef	Murdoch	Estimate the benefits of the non-use values of NMP and how choices may be related to socio-economic characteristics using Choice Modelling.	f.gazzani@murdoch.edu.au
Halkyard, B	Historical exploitation of turtles and lobsters at Ningaloo Reef	Murdoch	Assess the historical take of turtles and lobster from Ningaloo Reef.	brooke.halkyard@dec.wa.gov.au
Harcourt, R	Australian Telemetry and Acoustic Monitoring System	IMOS	Put in place both a fine and broad scale acoustic curtain at several sites along NMP to enhance research projects	rharcour@gse.mq.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
			identifying fine and large scale movement of particles and species	
Hashim, S	Survey of sediment quality in relation to mooring sites at Coral Bay, Western Australia	Curtin	Not Available	Not available
Heyward, Andrew	Coring of Porhytes to determine impacts of climate change	AIMS	Not Available	a.heyward@aims.gov.au
Hodgson, Amanda	Distribution and abundance of dugongs in NMP and Exmouth Gulf	JCU	Establish the abundance of dugong in NMP in relation to Shark Bay and Exmouth Gulf	a.hodgson@murdoch.edu.au
How, Jason	Movement patterns of lyretail grouper as they relate to marine park planning at Ningaloo Marine Park	ECU	Look at the movement patterns of the Lyretail grouper Variola louti to determine its home range, and see if existing sanctuary zone boundaries provide adequate protection for the species from fishing activities; Examine movement of fish across reef passes and determine whether they provide a natural barrier to fish movement	jason.how@fish.wa.gov.au
Huang, Zhi	Surrogacy Study of Carnarvon shelf (Ningaloo) infauna data	GA	Investigate the surrogacy relationships between marine physical variables and the distribution of marine infauna species.	zhi.huang@ga.gov.au
Humphries, Stuart	Suspension feeders and energy flow through reefs	UWA	Not Available	s.humphries@sheffield.ac.uk
Hutchins, B	Checklist of Ningaloo reef fish	WAM AIMS	Create a checklist of the reef fish at NMP	Barry.Hutchins@museum.wa.gov.au
Ivey, Greg	Transient coastal upwelling along Western Australia: the dynamics of the Ningaloo Current system	UWA	Conduct the first detailed study into the dynamics of coastal upwelling along the North West Cape by : 1) characterising the spatial and temporal variability of upwelling at Ningaloo through field experiments 2) Developing a three-dimensional circulation model of the Ningaloo region 3) using the model to develop suitable parameterizations to predict the meteorological and oceanic conditions responsible for generating upwelling (including annual frequency, duration and cumulative effects over seasons 4) applying the numerical model to assess the role of upwelling on the overall cross shelf exchange of material	greg.ivey@uwa.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
			between Ningaloo and offshore, and investigating how these exchange processes may be affected by forecasted climate related changes to regional meteorological and oceanic forcing.	
Jenner, Curt	Geographical and temporal boundaries for whales of Ningaloo	Centre for Whale Research	Identify the movement and distribution patterns of humpback whales at Northwest Cape and Exmouth Gulf and assess population abundance of 'D' stock	curtjenner@telstra.com
Johansson, Charlotte	Managing coral reefs - the importance of working with functional groups to maintain resilience	JCU	Assess potential variations within ecological functions for herbivorous populations on Ningaloo. Understand how these are structured and how they contribute to the build up of resilience.	charlotte.johansson@jcu.edu.a u
Kapeli Dani	Characterising phytoplankton productivity across Ningaloo Reef, Western Australia	UWA	Not Available	Anya.waite@uwa.edu.au
Keesing, John	An assessment of likely dispersal patterns for marine organisms based on hydrodynamic and population genetic models	CSIRO	Characterise the genetic structure throughout their WA range of two (or more) widespread urchin species with differing reproductive and larval biology and contrasting dispersal potential using DNA sequence information	john.keesing@csiro.au
Kingham, A	Sustainability of the wilderness experience : a case study in environmental stewardship	Curtin	Identify key environmental problems caused by camping and develop a set of guidelines to solve these problems through an on going stewardship program.	andrew@ComptonVale.com
Kuchling, Gerald	Temperature profiles of sea turtle nesting beaches in Western Australia	UWA, DEC	Provide an overview of temperature variation at sea turtle nesting beaches and allow rough estimates of sex ratio variations according to published male and female producing temperatures for the different species	kuchling@cyllene.uwa.edu.au
Langdon, Mark	The trophic ecology of the grazing sea urchin (Echinometra mathaei within NMP: comparing the effects of different closure regimes on urchin distribution and trophodynamics	Murdoch	Add to our understanding of coral reef ecology, in particular the role of sea urchins	M.Langdon@murdoch.edu.au
Lawrie, MS	Patterns of coastal tourism growth and multiple dwelling: Implications for informal camping along the Ningaloo coastline	UWA	Examine the factors underlying the growth and change of tourism in Ningaloo Region in relation to camping and how this information is used in planning and policy processes to address developmental pressures and resource use/planning conflicts.	Not available
Lee, Sam	Hydrogeology of the fractured and karst Tertiary limestone of aquifers of Cape Range	Curtin	Not Available	sam.lee@curtin.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
	focusing on the Water Corporation borefield in Exmouth			
Lewis, Anna	Sustainable camping along the Ningaloo coast: how campsite location, facilities and activities influence environmental impacts	Curtin	Assess campsite environmental impacts, and determine how impacts vary between sites and develop indicators to assist in future monitoring of campsite environmental impacts.	annarlewis@hotmail.com
Loneragan, Neil	Biophysical environment; fringing reef ocean to organism nutrient fluxes - a multi-disciplinary multi-scale approach (REEFLUX)	Murdoch	Not Available	n.loneragan@murdoch.edu.au
Lovelock, Cath	Nutrient limitation and impact of nutrient enrichment on arid zone mangroves	UQ	Understand the degree of connectivity between the terrestrial environment and estuaries in the arid tropics of Australia.	c.lovelock@uq.edu.au
Lowe, Ryan	Benthic productivity and calcification on Ningaloo Reef: role of oceanic forcing and response to climate change	UWA	Not Available	ryan.lowe@uwa.edu.au
Lowe, Ryan	Hydrodynamics of Fringing Reef Systems	UWA	Measure the dominant circulation and mixing processes in contrasting fringing reef systems at Ningaloo Reef and in Hawaii through a series of field experiments. Use a three-dimensional numerical circulation model of the both systems, validated using data from (1), to quantify the relative importance of the various forcing mechanisms that operate on this reef (i.e., wave, tide, wind and buoyancy-effects). Use the model to specifically investigate the transport of material on Ningaloo Reef (e.g. to study recruitment and nutrient dynamics) and conduct a risk analysis of processes that threaten its integrity (e.g. contaminant spills, wastewater discharge).	ryan.lowe@uwa.edu.au
Marriott, Ross	Stock assessment of spangled emperor	DoF	Assess spangled emperor stock in NMP for integrated fisheries management of the Gascoyne bioregion.	ross.marriott@fish.wa.gov.au
Matyear, Hayley	Algal diversity and succession in Coral Bay	Murdoch	Not Available	Not Available
Mawson, Peter	Sand temperature data loggers in turtle nesting beaches	DEC	Gather data on sand temperature over time at turtle nesting beaches	peter.mawson@dec.wa.gov.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
McCauley, Rob	Passive acoustics off Exmouth, whales and fish	Curtin, CWR	Gather information on marine mammal presence and movement patterns on the north west shelf	r.mccauley@curtin.edu.au
McElroy, Seamus	Economic and social aspects of recreational fishing in WA	UWA	Not Available	mcelroy.seamus@gmail.com
Meekan, Mark	Otolith analysis of Reef fishes in WA	AIMS	Determine whether long term datasets on otolith growth rate can be used to plot fish growth rate along the coast and identify impacts of climate change on fish populations.	m.meekan@aims.gov.au
Meekan, Mark	Whale sharks, migration and ecology, movements and behaviour of whale sharks with use of acoustic, satellite, PAT, crittercam and genetic tagging.	AIMS, CSIRO, NOAA	Determine movement and behaviour of whale sharks as part of the Whale Shark Management Program	m.meekan@aims.gov.au
Moore, Pippa	Using the past to understand the future: the effects of climate change on regional diversity patterns of coralline algae	UQ	Investigate the regional effects of climatic warming on the community composition and biogeographic range of crutose coralline algae along a 12 degree latitudinal gradient of Western Australia's coral reefs	pippa.moore@uq.edu.au
Norman, Brad	Whale sharks	Ecoceans	Collect baseline data on whale sharks at NMP by photo id, whale shark sex and size, deployment of data logging tags and collection of plankton samples to determine whale shark prey items	brad@whaleshark.org
Northcote, J	Socio-economic impacts of sanctuary zone changes in NMP: a preliminary investigation of effects on visitation patterns and human usage	ECU	Gather baseline data on human usage and tourism patterns to assess potential socio-economic impacts from the expansion of sanctuary zones in NMP on visitors and residents	j.northcote@ecu.edu.au
O'Shea, Owen	The ecology of demersal stingrays at Ningaloo Marine Park, Western Australia	Murdoch	Describe the distribution, abundance, movement patterns, demography and ecosystem impact of demersal rays at inshore, lagoonal habitats within NMP. Highlight key ecological functions and migratory behaviour of rays at multiple spatial scales through tracking, a demographic analysis and an exclusion experiment	o.o'shea@murdoch.edu.au
Pandolfi, John	Ecological effects of climate change on regional diversity patterns of WA coral reefs	UQ	Not Available	j.pandolfi@cms.uq.edu.au
Pattiaratchi, Chari	SERPENT: Scientific and Environmental ROV Partnership using Existing Industrial Technology	UOS, UWA, UOW,	International project in collaboration with oil and gas industry to undertake deep-sea research using ROV technology - offshore of NMP, commonwealth waters	chari.pattiaratchi@uwa.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
		UTS, Woodside, Santos, Chevron		
Pattiaratchi, Charitha	WAIMOS - West Australian Integrated Marine Observation System	UWA	The WA component of IMOS, real time monitoring concentrated along the Jurien-Cape Peron coastal stretch and 3 long term reference sites; Dampier, Rottnest and Esperance.	chari.pattiaratchi@uwa.edu.au
Penrose, Helen	Trophic connectivity via nekton in an arid zone estuarine landscape	UWA, UQ	Determine the relative importance of mangroves vs. cyanobacterial mats in supporting nekton in an arid zone estuary; Determine whether trophic connectivity via nekton is dependent on the spatial arrangement of the estuarine habitat mosaic; and Determine whether tidal movements of the giant shovelnose ray (Rhinobatos typus) are likely to represent an important biotic vector of energy transfer across the arid estuarine landscape.	h.penrose@uq.edu.au
Philp Kate	Ningaloo Reef as a plankton filter: changes in the size spectrum and community structure of zooplankton across a fringing reef	UWA	Not Available	Anya.waite@uwa.edu.au
Prince, Bob	Turtle tagging program	DEC	Continue a long term monitoring program of marine turtle nesting populations in NMP	Bob.prince@dec.wa.gov.au
Roberts, Rebecca	Economic strategies for disaster risk-reduction in coastal areas: a case study of Exmouth Gulf	Murdoch	Assess the socio-economics of vulnerability on communities who live in the coastal area of Exmouth	r.roberts@murdoch.edu.au
Rodger, K	Wildlife tourism and the natural sciences : bringing them together	Murdoch, STCRC	Develop our understanding and improve our use of science and monitoring in the management of wildlife tourism	k.rodger@murdoch.edu.au
Rose, James	Impacts of the Coral Bay boat ramp on adjacent shoreline and marine communities	Murdoch	Determine whether the boat ramp at Coral Bay has resulted in changes to the shoreline or marine communities adjacent to it.	j.rose@murdoch.edu.au
Rosser, N	Reproductive seasonality and biannual spawning of Acropora on two north-west Australian reefs	Murdoch	Not Available	Not Available

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Rossi, Vincent	A bio-physical characterization of water masses of Ningaloo reef in May 2010	UNSW	Use physical, biogeochemical and biological datasets to describe the water masses of Ningaloo reef.	v.rossi@unsw.edu.au
Rouillard, Denis	The use of hyperspectral imagery in detecting linkages between soils and marine sediments at Ningaloo	Murdoch	Produce a classification of distinct soil and sediment types within the Osprey Sanctuary Zone	h.kobryn@murdoch.edu.au
Sawstron, Christin	Phytoplankton size structure and productivity in the Leeuwin Current off Ningaloo Reef, WA	UWA	Quantify spatial patterns of phytoplankton size structure and productivity.	christin.sawstrom@uwa.edu.au
Scheffer, Sander	Coring of Porhytes to determine impacts of climate change - Exmouth Gulf	SCU	Not Available	sander.scheffers@scu.edu.au
Scheffers, Anja Marie	Establishing a high magnitude wave event at Coral Bay and the response of the adjacent coral reef ecosystem	JCU	Not Available	anja.scheffers@scu.edu.au
Shiell, Glenn	The spatial distribution and temporal shifts in the biology of Holothuria whitmaei Bell [Echinodermata: Holothuroidea], Ningaloo Reef, Western Australia	UWA	Determine the relative spatial distribution of sea cucumber in NMP and determine natural density patterns	glenn.shiell@oceanica.com.au
Sleeman, Jai	Modeling whale shark distribution	CDU	Not Available	jai.sleeman@cdu.edu.au
Smith Nadine	Mechanisms by which science is transmitted into community education programs for the purpose of capacity building	Curtin	Not Available	Nadine.smith@csiro.au
Smith, Leanne	Evaluating the effectiveness of the Jurabi Turtle Centre	Murdoch	Not Available	astraphobic@hotmail.com
Stewart, Brent	Range and habitats of whale sharks in the Eastern Indian Ocean	Hubbs SeaWorld Research Institute, CSIRO, AIMS, NOAA	Document the seasonal movements and habitat use of whale sharks at NMP between March and June using satellite tags	bstewart@hswri.org
Tonge, Joanna	The influence of place attachment on the management of marine parks and their hinterlands	Murdoch	Measure and understand visitor attachment to NMP and use this information to better inform management and development decisions	J.Tonge@murdoch.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
Travers, Michael	Composition of fish fauna in offshore waters of the Pilbara Kimberley coast	Murdoch	Not Available	M.Travers@murdoch.edu.au
Treml, Eric Anton	Reef connectivity and conservation: an empirical and theoretical synthesis	UQ	Evaluate connectivity (larvae dispersal) between reefs in the Coral Triangle and the GBR using physical and genetic methods and use this information to predict the impact of climate change on connections among reefs to prioritise their conservation	e.treml@uq.edu.au
Trocini, Sabrina	Conservation of the endangered loggerhead turtle (Caretta caretta): health assessment and hatching success of Western Australian populations	Murdoch Uni, DEC	Identify & quantify various biotic & abiotic risk factors that reduce hatching success of loggerhead turtles, Health assessment of nesting Loggerhead turtles on Dirk Hartog Island and in Cape Range NP	s.trocini@murdoch.edu.au
Underwood, Jim	Larval dispersal, gene flow and disturbance in two coral species in northern WA	UWA, AIMS	Investigate fundamental processes that influence the dynamics of survival, regeneration and evolution of species in the marine environment, the spatial scale and pattern of demographic connection among populations at NMP	underj01@student.uwa.edu.au
Usher, Kayley	Investigating the importance, diversity and host specificity of photosynthetic symbionts in marine sponges from tropical and temperate regions	DEC/UWA	Determine; the percentage of photosynthetic sponges on temperate and tropical reefs, diversity of photosynthetic symbionts of sponges, biogeography of symbiont classes, the abundance of symbiont classes and range of host sponges.	kusher@cyllene.uwa.edu.au
van Keulen, Mike	Seagrasses and macroalgae of Ningaloo	Murdoch Uni	Not Available	keulen@murdoch.edu.au
VanKeulen, M	Metabolic consequences and vulnerability to stress during reproduction in spawning corals	Murdoch	Establish baseline rates of photosynthesis, respiration and calcification and overall oxygen demand of the Coral Bay reef system. Examine the effect of temperature, spawning slicks, sedimentation and nutrient influx on these processes.	keulen@murdoch.edu.au
Waayers David	A holistic approach to planning for wildlife tourism: a case study of marine turtle tourism and conservation in the Ningaloo Region, WA.	Murdoch	Examine three fundamental aspects of wildlife tourism: stakeholder collaboration, the importance of collecting baseline data and detecting tourism related impacts on wildlife using the turtle tourism industry in Ningaloo region as a case study.	Not Available
Waite, Anya	Ocean-reef fluxes at Ningaloo	UWA	Quantify the supply of food supplied as planktonic particles to the coral community at Ningaloo Reef through determining the sources of food particles and dissolved nutrients across the	Anya.waite@uwa.edu.au

Principle Researcher	Title	Institution	Objectives	Contact details for PI
			reef and by tracking ocean particle and nutrient sources into the coral reef food web	
Webster, Fiona	Effect of algae, herbivores and nutrients on the settlement and survival of coral	Murdoch	Investigate the effect of fish predators, urchin densities and algal cover on coral recruitment.	Not Available
Williams, Alan	Southern Surveyor Voyage - 2005: Initial summary of data collected in the Ningaloo Commonwealth MPA	CSIRO	Test hypotheses on the evolution and biogeography of WA's marine biodiversity; Validate and refine CSIRO's optimised methodology for mapping deep water benthic ecosystems to enhance its application to natural resource management; Document the benthic biodiversity and identify areas of high conservation values in the SW bioregion for Commonwealth MPA declaration; Validate and permit refinement of marine bioregionalisation for the SW bioregion	Alan.williams@csiro.au
Wilson, Shaun	Effects of fishing and climate change on reef fish	DEC	Determine how habitat degradation instigated by climate change and changes in predation instigated by fishing pressures effect the composition of the predator community on WA coral reefs. Assess diet of predatory species targeted by fishers. Identify microhabitats preferentially used by juvenile fish. Assess how variation in fishing pressure and habitat complexity/composition influence predation rates on juveniles.	shaun.wilson@dec.wa.gov.au
Wilson, Shaun	Preliminary assessment of disease in Australian corals: Ningaloo Marine Park	DEC	Investigate the prevalence and types of disease affecting corals in Western Australia.	shaun.wilson@dec.wa.gov.au
Wyatt, Alex	Trophic ecology of coral reefs: the role of oceanographic-to-organism scale processes in trophodynamics and benthic-pelagic coupling	UWA	Link benthic ecology and biological oceanography to elucidate the extent and mechanisms by which coral reefs are nutritionally linked to the surrounding pelagic environment and susceptible to its alteration	asjwyatt@iinet.net.au