Discovering **Ningaloo**

LATEST FINDINGS AND THEIR IMPLICATIONS FOR MANAGEMENT

Ningaloo Research Program
Progress Report
2008

better science better decisions

Western Australian Marine Science Institution, CSIRO's Wealth from Oceans National Research Flagship, Department of Environment and Conservation and Murdoch University.

Ningaloo Research Program Progress Report

Discovering Ningaloo: Latest findings and their implications for management

Edited by Kelly Waples, Marine Science Program Department of Environment and Conservation and Edwina Hollander.

Published by the Ningaloo Research Coordination Committee.

This report represents current findings from a selection of the research currently underway at the Ningaloo Marine Park. It is not an exhaustive summary of all research that is currently occurring, or recently completed, at this location.

For further information on these research projects or to download a copy of the progress report, visit the Ningaloo Research Website: http://www.ningaloo.org.au

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Acknowledgements

Many people have contributed to the Ningaloo Research Program from its inception in 2005 through to the vast array of research currently underway. 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 the Ningaloo Marine Park. We also thank the Western Australian State Government (through WAMSI), CSIRO (through the Wealth from Oceans Flagship) and all the research collaborators for providing the funding to support the research in this report and Murdoch University for providing the venue for the Symposium.

We would also like to thank all those who have assisted in bringing this progress report together, in particular Alan Kendrick for assistance reviewing manuscripts, Irene Abraham and Wendy Steele for ensuring manuscripts were delivered and Sue McKenna for her assitance in design and editing.

Discovering **Ningaloo**

LATEST FINDINGS AND THEIR IMPLICATIONS FOR MANAGEMENT

Ningaloo Research Program

Progress Report

western australian marine science institution

National Research FLAGSHIPS Wealth from Oceans

CSIRO

Department of Environment and Conservation

Our environment, our future

Murdoch University

Foreword

The Ningaloo Reef is one of the world's largest fringing coral reef systems. The marine and coastal environment of Ningaloo has long been identified as an important marine biodiversity asset of Western Australia. This was formally recognised with the establishment of the Ningaloo Marine Park in 1987. A review of the marine park management plan in 2004 led to extension of the park's boundaries, revision of its zoning plan and improved funding for ongoing management.

At the same time as the release of the revised management plan, the Western Australian Government committed $5 million over four years for research to improve our scientific understanding and, ultimately, the management of human use of this iconic region. This investment blossomed into the current Ningaloo Research Program which is worth over $30 million and includes a collaboration between State Government departments, the CSIRO Wealth from Oceans Flagship Program, the Australian Institute of Marine Science, local WA universities and industry partners.

The two main elements of the Ningaloo Research Program are managed through Node 3 of the Western Australian Marine Science Institution (WAMSI), for which the WA Department of Environment and Conservation is the lead agency, and the CSIRO Wealth from Oceans Flagship Collaboration Fund Cluster, led by Murdoch University. The WAMSI node 3 Research Program is largely based on the scientific information requirements identified in the marine park management plan. The integrated research program was developed through a consultative process involving scientists and resource managers and covers a range of topics, all highly relevant to the long-term conservation and management of the Ningaloo Marine Park and surrounding area. The work in the Collaboration Fund Cluster, entitled "Reef use, biodiversity and socio economics for integrated management strategy evaluation of Ningaloo", seeks to build on this biophysical science by integrating understanding of the social and economic factors underlying the Ningaloo region.

The papers contained within this report provide examples of the vast array of work that is currently underway, highlighting the implications for management that will ensure the Ningaloo Marine Park remains a healthy ecosystem that is valued in Western Australia and nationally. From this report, it is apparent that the objectives of the Ningaloo Research Program are well on the way to being met and already producing significant results.

This research program is an outstanding example of how cooperation and collaboration combined with support, both financial and otherwise, can make key advances in science that will lead to better decisions and thus better management of our natural areas and their resources.

Keiran McNamara

Keiran McNamara
Director General
Department of Environment and Conservation, WA

Dr Kate Wilson
Director
CSIRO Wealth from Oceans
National Research Flagship

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Introduction

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, snorkeling and other outdoor activities. Balancing conservation of this unique marine ecosystem with sustainable development of the region is a major challenge.

Background to the Ningaloo Research Program

The Ningaloo Marine Park 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 Ningaloo Research Program was established to fill these information gaps, recognising that a science-based understanding of the Ningaloo Marine Park 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.

The Ningaloo Research Program was initiated by an investment of $5million from the Western Australian Government into a four year research program to address key scientific questions highlighted in the marine park management plan. This initial investment has been enhanced by significant co-investment from research institutions, government departments, WA universities and industry to now equal more than $30million worth of research over five years.

The program brings together Ningaloo-related research activities being conducted through:

- State Government departments;
- the Western Australian Marine Science Institution (WAMSI);
- the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster;
- Australian Institute of Marine Science (AIMS);
- local WA universities; and
- industry.

The research plan that makes up the program was developed, through consultation with the marine science community and relevant state government departments and tackles broad, ecosystem-based questions that will strengthen the scientific foundation which underpins the management of the Ningaloo Marine Park.

Linking science and management

A key objective for the Ningaloo Research Program is to integrate knowledge of oceanographic processes, biodiversity, reef use and socio-economics into the management framework for the Ningaloo region. This can only occur if knowledge is transferred between scientists and managers in a way that will influence policy, planning and management activities. Thus the link between science and management is critical to the success of the Ningaloo Research Program and also to the recognition by the State Government that their investment in Ningaloo has been worthwhile.

The Ningaloo Research Coordinating Committee (NRCC) was formed to provide some oversight for the Ningaloo Research Program and coordination of the research conducted through the large number of participants. This committee has members from WAMSI, DEC, CSIRO Wealth from Oceans Flagship Program, Murdoch University and AIMS. The main aim of the NRCC is to ensure that the research conducted at Ningaloo is well integrated and coordinated and that there are clear pathways and exchange among researchers, management and the broader community.

The integration of research is promoted through the annual Ningaloo Research Symposium which was inaugurated in 2007. These symposia have provided an ideal venue to bring together the broad range of fields of expertise conducting research in the region so that they may share ideas, emerging findings and promote collaboration and co-operation. They also provide an opportunity to include resource managers and those with an interest in the application of science outcomes to the conservation and management of this important area.

The theme for the recent Ningaloo Research Symposium held in May 2008 was *Discovering Ningaloo: latest findings and their implications for management*. This event was well attended and provided a strong overview of the current work underway at Ningaloo along with recent findings.

This publication is a follow-on from the Second Annual Ningaloo Research Symposium. Its purpose is to highlight the advances in knowledge that are being made through the Ningaloo Research Program. The following short papers each describe a different aspect of research under investigation at Ningaloo, present current findings and discuss the implications of these findings for management. This report should be considered as a progress report only because many of these projects are still underway and the current findings are preliminary with further research and analysis yet to be completed.

It is clear from these preliminary papers that the investment in the Ningaloo Research Program is producing very interesting and applicable results. Already we have a better appreciation for the rich biodiversity present in deepwater benthic habitats, improved bathymetric and habitat maps for the marine park, the development of a suite of integrated models to evaluate different development and management options, and a fuller understanding of the reef's links with oceanic processes.

We are gaining the information on biodiversity and community structure and distribution to be able to make well considered assessment of the effectiveness of sanctuary zones within the park. We have a fuller appreciation of human use patterns in the park and the flow on economic impacts of tourism on the local and regional economy. Altogether the Ningaloo Research Program is well on the way to meeting its research commitments and providing the information needed for management.

The NRCC will continue to place emphasis on ensuring that this science is captured and integrated into management policies and initiatives. The Ningaloo Research Program is committed to making a difference at Ningaloo Marine Park, and more broadly to the region. We rely on the scientists to assist by providing the information and research capacity that will improve our understanding of the region and on the resource managers to consider this information and its interaction with tried and new management strategies.

This progress report is one step along that process that we hope will stimulate further discussion and interaction between scientists, resource managers and policy makers. We are confident that, given the commitment and dedication by both scientists and resource managers that the Ningaloo Research Program will produce quality science that will support better decisions.

On behalf of the NRCC

Prof Neil Loneragan, Leader Ningaloo Collaboration Cluster, CSIRO Wealth from Oceans Collaboration Flagship Program

Dr Bill de la Mare, Theme Leader, Marine Nation – Ocean-based Regional Marine Development and Growth, CSIRO Wealth from Oceans National Research Flagship

Dr Chris Simpson, Leader, Node 3 WAMSI: Department of Environment and Conservation

Dr Kelly Waples, Science Co-ordinator, Node 3 WAMSI; Department of Environment and Conservation

Biodiversity

Effects of zoning on targeted fish populations in the Ningaloo Marine Park

Russ Babcock, **Mick Haywood, Mat Vanderklift, Geordie Clapin, Matt Kleczkowski, Darren Dennis, Time Skewes, Dave Milton, Nicole Murphy, Richard Pillans, Andrew Limbourn**

CSIRO Marine and Atmospheric Research

Abstract

*Populations of fish targeted by recreational fishers in the Ningaloo Marine Park, were surveyed In 2006 and 2007 to assess whether populations from sanctuary zones established in 1990 differed from those in areas that were open to fishing. Herbivorous fish from major families in this functional group were also censused. A further aim of the work was to provide baseline data on populations from newly declared sanctuary zones that could be used to assess future trends in protected populations as well as across the park as a whole. Over 900 sites were surveyed over this time using underwater visual census (UVC), with effort focused on 12 sanctuary zones distributed along the length of the park. Among the species most commonly targeted by anglers there was an overall difference in abundance for just two species: the spangled emperor (*Lethrinus nebulosus*) and the yellow tailed emperor (*L. atkinsoni*), showed 2 and 3 fold increases respectively. This result applied only to fish greater than minimum legal size, not for the population as a whole. Given the fact that more than 15 years have elapsed since the implementation of no-take zoning in the park these differences are relatively small. Possible reasons for the small effect size in some species and lack of effect in others include high rates of cross-boundary movement, lack of compliance with zoning, relatively low overall fishing pressure in the area, and the high variability encountered among samples.*

Project description

The Ningaloo Marine Park 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 in practical terms their main impact on human usage has been to restrict levels of commercial and recreational fishing within the park. Consequently it is essential that DEC and other state agencies assess the response of fished populations in order to evaluate the effectiveness of zoning measures for a range of exploited species, and across the various management zones.

The purpose of this project was to provide the first data point in a long-term data set. These data will become an integral part of future research and monitoring of the Ningaloo Marine Park, including not only assessing the ecosystem effects of fishing, but also in terms of evaluating the effectiveness of zoning for biodiversity conservation, and for assessing the implications of zoning for fish populations and for fishing outside sanctuary zones. The surveys have provided data not only for newly established zones, but also for previously established zones within the park. Where possible the survey will build on existing data sets, though these are limited in scope and spatial extent some do exist from the late 1980s.

Survey sites in the Ningaloo Marine Park were selected from among coastal areas stretching from Gnarraloo to the Muiron Islands. Potential sites were initially identified from aerial photo mosaics, benthic habitat maps, and marine park zonings for

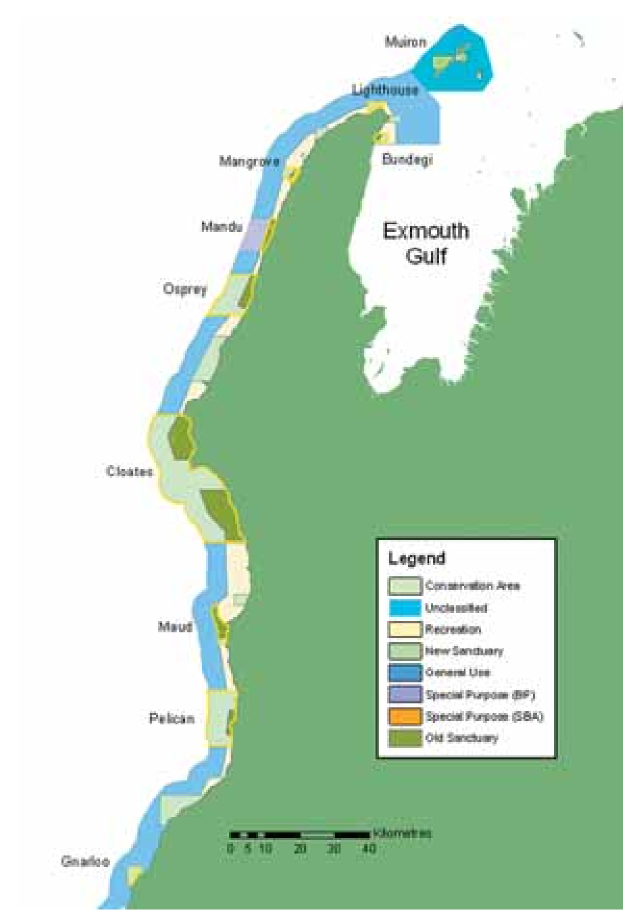


Figure 1.

Ningaloo Marine Park. Sanctuaries sampled in this set of surveys are outlined in yellow.

both new and old plans. Sites from among andomly generated points were then selected such that the effects of several factors could be tested. These factors included management zone, age of management zone, distance from zone boundary, and habitat. Within each management zone, samples were stratified by habitat, and distance from zone boundary. The habitat factor included three levels including; outer reef slope, shallow lagoon, and channel.

Fishes within the Ningaloo Marine Park were sampled using underwater visual census methodology (UVC). This involved a single SCUBA diver swimming along a 100m x 10m belt transect, identifying, counting, and estimating the total length of fishes within the transect. Censuses focused on several discrete guilds of fish rather than the entire fish assemblage and included major predatory fishes that are targeted by recreational fishers, as well as the main herbivorous families. Predatory fishes surveyed included those from the families; Lethrinidae, Lutjanidae, Serranidae, Carangidae, Scombridae, Labridae, Haemulidae, and Carcharhinidae while the herbivorous families surveyed included; Scaridae, Siganidae, Acanthuridae, and Kyphosidae.

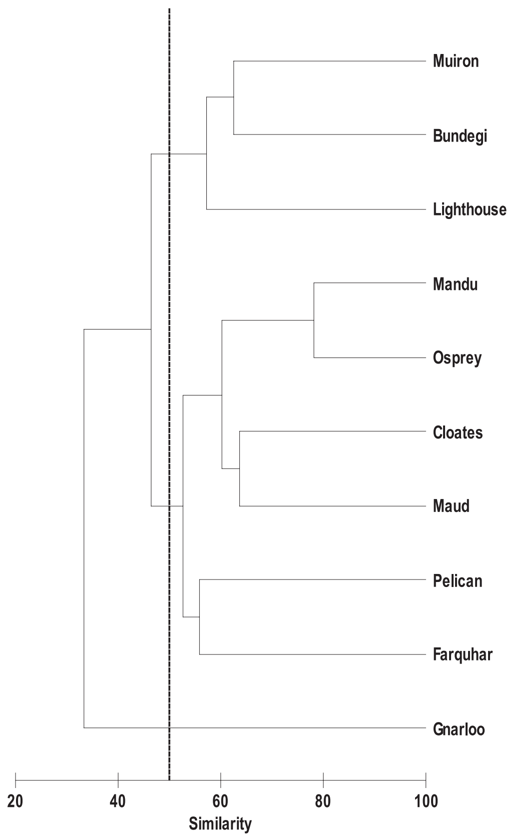


Figure 2.

Geographic trends in fish assemblages. Data are for reef slope habitats only and show that assemblage similarity changes markedly along a north-south gradient.

Current findings and their implications for management

The surveys showed that there was a clear differentiation of fish assemblages between the north and south of the park (Fig. 2). This finding supports the increased level of protection afforded to areas at the north and south of the park which were previously under-represented by sanctuary zoning.

Comparisons of the abundance of one of the key targeted species, the Spangled Emperor, between 1987 and 2006-07 showed that densities appeared to have declined by approximately 50% over that period of time (Fig. 3). This decline was evident over both sanctuary and recreational zones.

Among populations of targeted fish species the overall comparison for all of the sanctuary zones established in 1989 showed that the density in sanctuary zones was greater only for two emperor species. The yellow tailed emperor (*L. atkinsoni*) was around three times more abundant in the sanctuary zones than in other areas while individuals of the iconic target species the Spangle Emperor (*L. nebulosus*) above legal size were around twice as common inside sanctuary zones (Fig. 4). For Spangled Emperor most of this difference was due to large density differences in lagoon habitats.

Knowledge transfer

The data provided by this project will be most relevant to government agencies and resource managers such as DEC and WAF who are responsible for managing the biodiversity values and ecologically sustainable development and use of marine resources in the Ningaloo region. We anticipate that

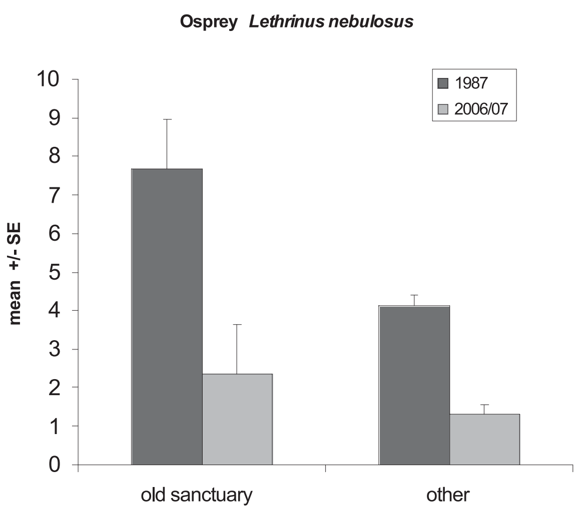
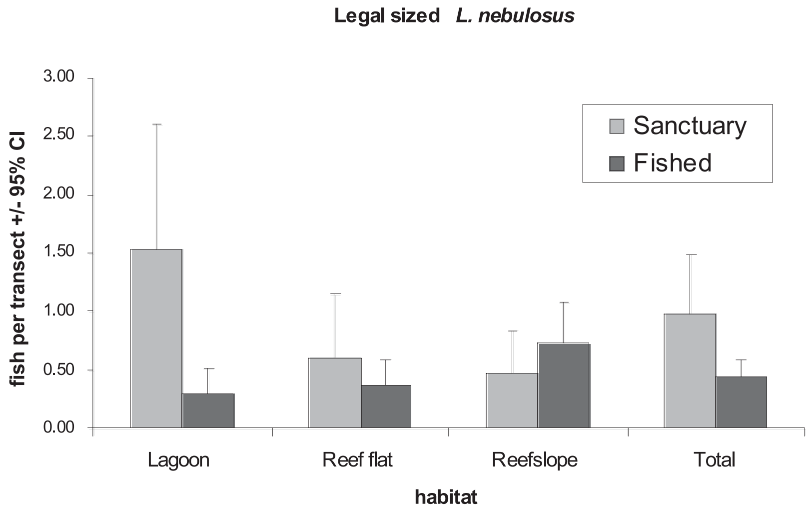


Figure 3.

Historical comparison of density of Spangled Emperor at the Osprey Sanctuary Zone.

Figure 4.

Abundance of legal sized (>42cm FL) Spangled Emperor in old sanctuaries (established 1989) relative to other marine park zones in adjacent regions.



the scientific community and the general public will be interested in the results which directly address some of the key concerns of the public surrounding the rezoning, and also underpin understanding of key scientific issues such as assessments of resilience. The data will also be useful to the construction of numerical models of Ningaloo.

Next stage

The next stage of the project is to complete the analysis of the data and prepare a series of papers for publication in scientific journals. It will also be important to consult with resource management agencies to develop plans for ongoing studies to detect trends in the status of targeted fish species and other biodiversity assets within the Ningaloo region.

Acknowledgements

We would like to acknowledge the support of DEC Exmouth staff as well as the Communities of the Ningaloo region; charter operators, pastoral stations and other providers of accommodation (particularly Yardie Creek Caravan Park).

Lagoonal and cross shelf patterns in the trophic structure of demersal fish assemblages on the Ningaloo Reef

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3. CSIRO Marine and Atmospheric Research

Abstract

We aim to quantify significant patterns in the distribution and abundance of target demersal fish in relation to two sanctuary zones and across habitats and depths of the continental shelf of Northern Ningaloo Reef. Using one consistent approach, stereo-baited remote underwater video systems (stereo-BRUVS) we found significant patterns in the structure of fish assemblages. Overall, biomass is concentrated in upper trophic levels of the fish assemblages the further offshore the habitat. Ontogenetic habitat shifts in higher trophic levels including Lutjanidae*,* Serranidae*,* Lethrinidae *and* Carangidae *are common often with smaller fish found in near shore habitats and larger fish in offshore habitats. Habitat partitioning between species from the same families contribute significantly to differences between habitats often with smaller bodied species found in higher frequencies inshore and larger bodied species in offshore habitats. Fishing possibly contributes towards this general pattern as well with the observation that biomass of certain target species, generally from higher trophic levels, is significantly less in fished areas relative to notake zones within the lagoon. All these processes appear to contribute towards a pattern of significantly increasing biomass in upper trophic levels with increasing water depth particularly within reef habitats.*

Project description

The objectives of this research are to describe the trophic structure of fish assemblages within and adjacent two lagoonal no-take areas and across continental shelf habitats of the northern Ningaloo Reef. Specifically we aim to determine how protection from fishing in the lagoon, and habitat and depth across the continental shelf influence fish assemblages. We randomised sampling with stereo-BRUVS stratified by 16 depth/habitat categories at four locations down to 100+m water depths. A total of 340 stereo-BRUV samples were collected, including 144 samples from the lagoon where we sampled 6 main habitats inside and outside 2 no-take zones established since 1987. Habitat/depth combinations were based on habitat maps derived from georeferenced diver and towed video, acoustics and aerial imagery (Curtin Uni and Australian Institute of Marine Science). We derived relative abundances of fish and fork lengths then used these to calculate biomass using known length-weight curves (Fishbase, 2008).

Current findings and their implications for management

Species relative abundance inside the two no-take reserves were highly significantly different to adjacent fished areas driven by *Gnathanodon speciosus*, *Lutjanus fulviflamma*, *Carangoides fulvoguttatus*, *Epinephelus rivulatus*, *Lethrinus nebulosus* and *L. atkinsoni* (Figure 1). Biomass of these targeted reef fish from higher trophic levels was relatively low in lagoonal habitats which supported an abundance of *Acanthuridae*, *Labridae*, *Scaridae*, *Pomacentridae*, *Caesonidae* and *Chaetodontidae*. In contrast offshore habitats have fish biomass concentrated within higher trophic levels including *Carangidae*, *Lethrinidae*, *Lutjanidae* and *Serranidae* (Figure 2). These findings contradict our expectation that shallow coral reefs should support higher biomass at higher trophic levels due to the increased primary productivity of shallow phototrophic coral reef habitats. A number of processes contribute to these patterns. Ontogenetic habitat shifts are characteristic of many species at higher trophic levels which display increasing size with depth across the shelf such as the *Lethrinidae* (Figure 3). Habitat partitioning between species from the same family also occurs, for example *L. atkinsoni* is a coral reef specialist, *L.miniatus* is only found offshore and *L. nebulosus* is found everywhere (Figure 4).

Food availability is likely to contribute to this pattern with offshore habitats supporting larger bodied fish prey, increased sediment infaunal and invertebrate diversity and abundance and seasonal nutrient rich coldwater upwelling. Impacts from fishing pressure in shallow water could also contribute towards this observed pattern.

A number of species particularly those from higher trophic levels display ontogenetic habitats shifts across the shelf. Studies on shallow coral reef fish assemblages particularly those on effects of no-take zoning often only focus on shallow habitats in less than 10m water depth and are likely to be sampling a small fraction of the target species population structure. These data also emphasize how increasing impacts on specific shallow coral reef habitats might disrupt recruitment of adults into spatially distinct offshore habitats at depths greater than previously thought. This research emphasizes the need to consider a greater diversity of habitats at a broader shelf scale when implementing marine

Figure 1.

Target species total biomass based upon species relative abundance, fork length and Length-weight relationships summed across 6 habitats within and adjacent two sanctuary zones.

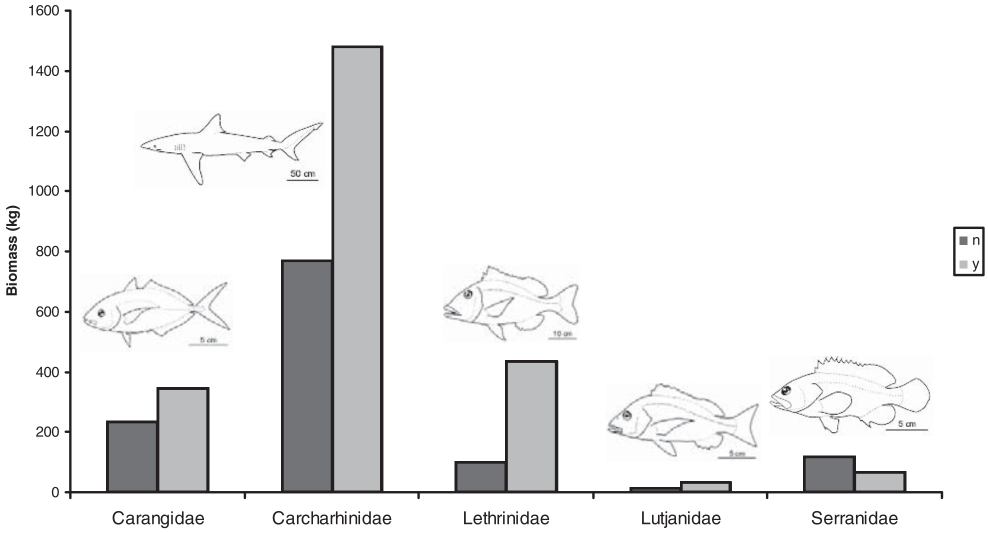
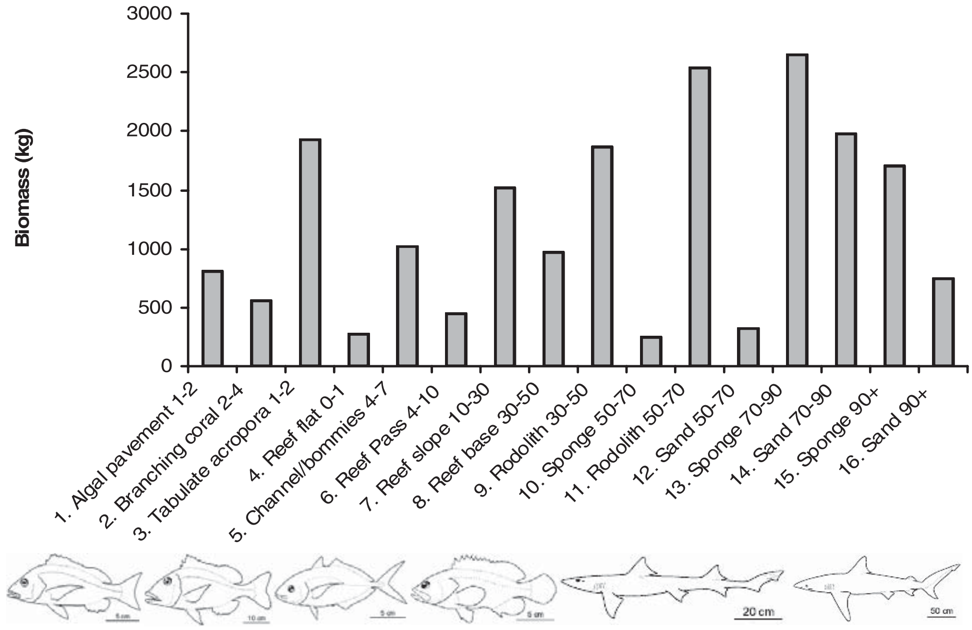


Figure 2.

Total biomass in upper trophic levels based upon species relative abundance, fork length and length-weight relationships summed across 16 depth/habitat categories and including Lutjanidae, Lethrinidae, Carangidae, Serranidae, Traikidae *and* Carcharhinidae.



parks and monitoring for their efficacy in protecting fished and non-fished assemblages.

Knowledge transfer

These data will contribute significantly to management of Ningaloo Marine Park in particular in assessing the comprehensiveness, adequacy and representative of current marine park zoning for state waters. This is relevant to the Department of Environment and Conservation and Department of Fisheries. This research contributes significantly to understanding of the effects of fishing in shallow lagoon habitats and is useful to ongoing Commonwealth Science and Industrial Research Organization research on ecosystem effects of fishing. It also helps define fish biodiversity in deeper waters and is relevant to concurrent research by the Australian Institute of Marine Science, Western Australian Museum and Curtin University. This process is also of relevance for defining information needs for the management of Commonwealth waters of the Ningaloo Marine Park and is of relevance to the Department of Environment, Water, Heritage and the Arts and Australian Fisheries Management Authority. These data are also of interest to a broad range of stakeholders including non-government organizations and recreational fishers. Most if not all these groups have had the opportunity to attend presentations based on this research, in addition specialist scientific audiences will be reached through journal publications and a PhD thesis. All project metadata and outputs will be databased and lodged with relevant data

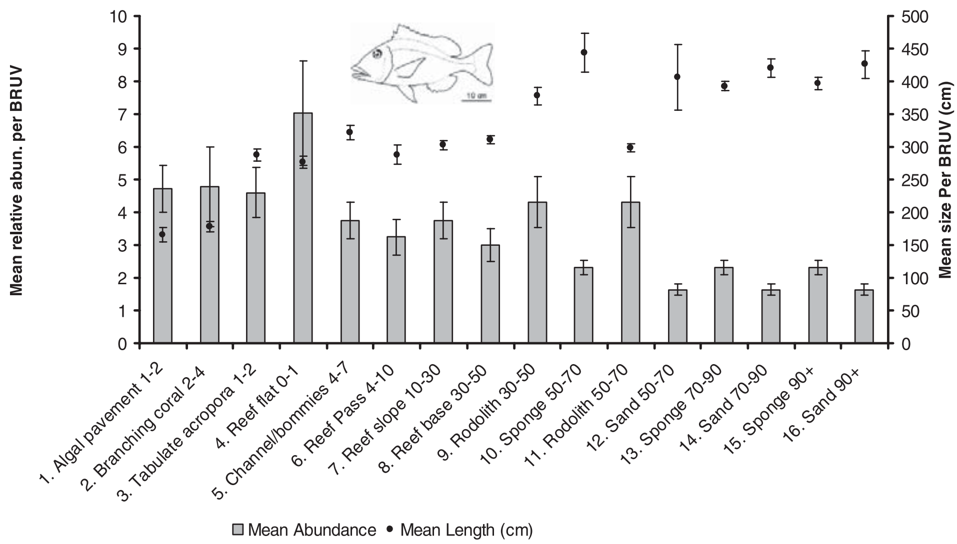


Figure 3.

Increasing size and decreasing abundance in Lethrinids across continental shelf habitats of northern Ningaloo Reef reflecting ontogenetic habitat shifts in many species including L. nebulosus*,* L. atkinsoni *and* L. miniatus.

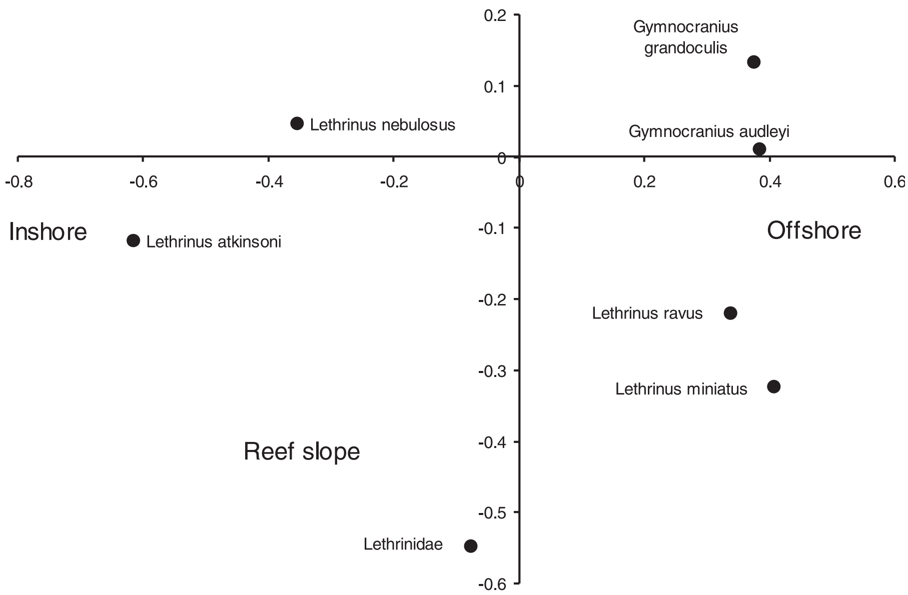


Figure 4.

Six species of Lethrinidae *that contribute significant differences between habitat/depth zones (rCAP 1 or 2 >0.25) suggesting evidence for habitat partitioning between species of the same family.*

archives to ensure preservation of data for future research. Visual multimedia based on video footage will also be available in this way and would be useful for presentations by managers and politicians.

Next stage

This research will continue with broadscale surveys across the outer reef and shelf fish assemblages along the length of Ningaloo Marine Park. The goal of this research is to utilize habitat mapping data to plan sampling of fish assemblages using stereo-BRUVS and Stereo-drift video associated with discrete habitat types. This would be in addition to inshore surveys utilizing stereo-BRUVS and stereo diver operated video to assess effectiveness of zoning in protecting inshore fish assemblages associated with different habitats.

Acknowledgements

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Intertidal invertebrates surveys

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2. School of Plant Biology, University of Western Australia
3. Department of Environment and Conservation, Western Australia

Abstract

Intertidal rocky platforms at Ningaloo Marine Park are easily accessible and potentially prone to impacts of human activity. This project examines the abundance of individual species and the composition of assemblages of species on the platforms, with the aim of describing patterns of spatial and temporal variability that will be useful if future sampling is done to detect natural and anthropogenic spatial differences and temporal changes. Our preliminary sampling at 18 sites in August 2007 revealed a rich fauna (117 species, mostly molluscs), with an overall abundances of about 12 individuals per one square metre. There was considerable spatial variability in abundances and in composition of assemblages, even between closely adjacent sites. These features are a challenge to determining causes for differences and changes that we hope our future investigations can meet.

Project description

This project seeks to provide an inventory of organisms on rocky, intertidal shores, both within and outside sanctuary zones, by making quantitative estimates of abundances of the assemblages of species. Our ultimate goal is to provide information about spatial and temporal variability in the abundances of particular species, and in the composition of assemblages of species. This information can be used to design future sampling that will be able to detect differences among sites and and temporal changes within sites.

Figure 1.

Rocky intertidal platform at Bateman Bay, Ningaloo Marine park.

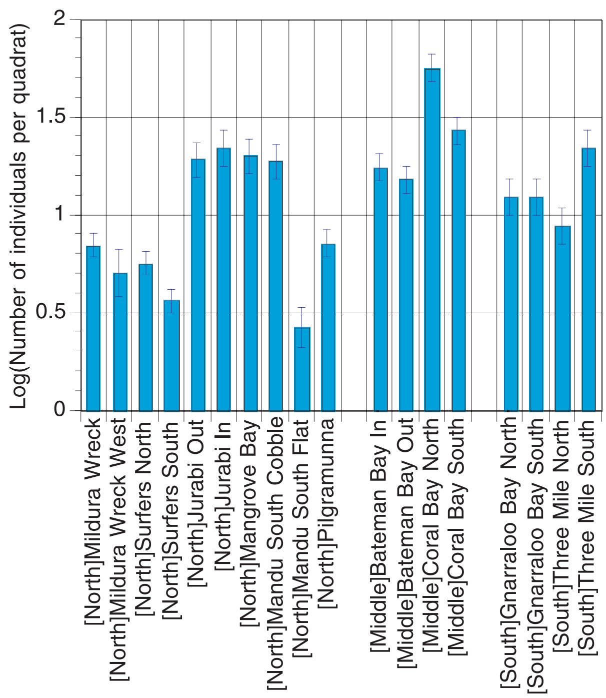

Figure 2.

Mean ± s.e. of the logarithm of the number of individuals per quadrat for the 18 sites.

Current findings and their implications for management

Our preliminary study in August 2007 involved 10 sites in the north, 4 sites in the middle and 4 sites in the south of Ningaloo Marine Park, one of which is shown in Figure 1. This initial sampling involved 452 1 m2 quadrats, in which we found 117 species distributed among the 12,867 individuals. The three regions differ in average abundance of organisms, with the equivalent of 8.3, 25.1 and 13.2 individuals per square metre in the north, middle and south regions respectively (Figure 2). The unexplained variability was greatest among quadrats within sites, double that for sites within regions. These patterns were mainly due to large numbers of mussels and ceriths in some of the quadrats at sites in the middle section of the park that were not present at sites in the north and south.

The numbers of species per site varied considerably too, and our collections were characterized by many rare species; forty-one of the 117 species were represented by single individuals. Analyses of species accumulation curves for a sample of 250 individuals at each site for the three regions gave mean numbers of species ± s.e. of 23.3 ± 2.4, 14.7 ± 3.2, and 17.5 ± 3.8 per site for north, middle and south regions; these

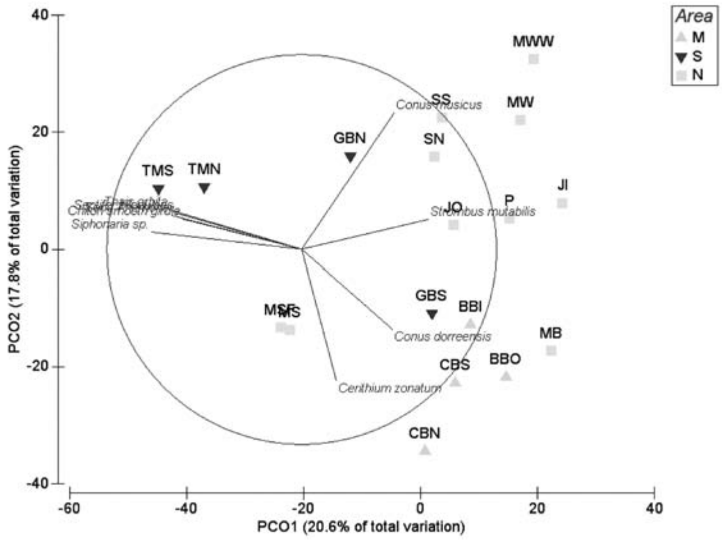

Figure 3.

Principal Coordinate Analysis or metric Multidimensional Scaling (an unconstrained ordination) of the eighteen sites. The symbols for the sites are coded for north, middle and south as indicated in the key. The letter codes refer to the individual sites. The radiating lines within the circle are an overlay of the correlations of the species with the axes. Only species with correlations > 0.6 are shown. The four species to the left are Thais orbita*,* Septifer bilocularis*,* Siphonaria *sp., and a chiton. The species to the right from top to bottom are* Conus musicus*,* Strombus mutabilis*,* Conus dorreensis*, and* Cerititum zonatum*.*

differences are not statistically different. Only 23 species were found in all three regions, and 45, 12, and 15 species were found only in the north, middle and south regions respectively.

We used the log (x+1) transform of the abundances of the species at each site, adjusted to the numbers per 20 1 m2 quadrats, to show how similar the collections of the species were among sites. An unconstrained ordination of the sites showed that the sites are only vaguely grouped by the regions, as judged by the distances apart that the sites are in Figure 3. The four middle sites are most coherently clustered. Even the pairs of sites that are spatially adjacent (<~300 m apart) [Mildura Wreck and Mildura Wreck West (MW, MWW), Surfers North, Surfers South (SN, SS), Jurabi Out and Jurabi In (JO, JI), Coral Bay North and Coral Bay South (CBN, CBS), and Three Mile North and Three Mile South (TMN, TMS)] are separated in the figure.

Figure 3 also shows which of the species are highly correlated with the multivariate axes. A whelk, a mussel, a limpet and a chiton are associated with the left end of the horizontal axis (where the sites at the extreme south are located), and a cone and a stromb (north sites), and another cone and a cerith (middle sites) are associated with the right end of the horizontal axis.

The preliminary study revealed high levels of spatial variability in numerical abundances of species on rocky intertidal shores at all the scales that we considered (among quadrats within sites, among sites within regions and among regions within Ningaloo Marine Park, 10 metres, 10 km and 100 km apart). This feature will make detecting causes of spatial differences difficult, and restrict discrimination of spatial heterogeneity to large differences, and so will make interpreting influences of potential impacts difficult.

Because our collections of the assemblages of species on the rocky platforms have so many rare species (single individuals per species), continued sampling will add to the inventory of species present at the sites that we examine. The species accumulation curves suggest that our sampling effort would need to be increased substantially if we aimed to detect all the species at a site, and, in fact, this is not and should not be an aim for our study, or for any future monitoring scheme.

Overall, this preliminary study revealed that each site appears to have unique combinations of abundances and species, and even closely adjacent sites can differ considerably.

Knowledge transfer

At this preliminary stage of our study, we do not yet have information that can be immediately useful to others. However, we are in the process of producing a field guide with photographs illustrating all the species that we detect in our surveys. When this is refined and tested, it should be useful for anyone interested in the fauna of the rocky intertidal platforms.

Next stage

Our future work will involve i) sampling the same and additional sites to augment the spatial and temporal coverage of intertidal rocky platforms at Ningaloo Marine Park, with special attention to confirming that comparable platforms do not exist inside and outside all of the sanctuary zones, ii) developing sampling schemes that detect more of the species targeted by shell collectors (e.g., cowries, large ornate shells) and fishers (e.g. octopus), and iii) collecting information about the physical features of the sites that might help explain the large spatial heterogeneity that exists.

Acknowledgements

We thank the staff of Department of Environment and Conservation from Exmouth and Coral Bay who assisted with the sampling.

Biodiversity in the deepwater benthic habitats of Ningaloo Marine Park

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Project description

Assessment of deep water biodiversity is a key priority area identified in the Ningaloo Research Plan. Very little is known about seabed biodiversity below diving depths in Ningaloo Marine Park, yet the majority of the marine reserve's declared area lies below 20m depth. A pilot study of the marine park by AIMS in 2004 (Rees et al, 2004) identified the existence of significant areas of phototrophic benthos, including corals, down to depths of around 40m and a range of possibly unique but patchily distributed filter feeding communities, such as sponge and soft coral gardens, across the shelf to depths of approximately 200m. This preliminary study also noted evidence of patterns in the fish communities associated with habitat and depth.

The current multi-year study is providing baseline information on biodiversity values in the deeper WA waters of the marine park seawards of the reef crest, including the currently declared offshore sanctuary zones. To achieve this, surveys will cover all deeper water sanctuary zones and adjacent non-sanctuary zones. A collaborative approach led by AIMS and involving the WA Museum, UWA and Curtin University is documenting habitat extent and quality, developing improved maps of bathymetry and establishing an initial reference collection of the major species associated with the seabed. The surveys will generate maps of the biophysical domains using acoustic data and sediment collections, which will be overlaid with biodiversity data from direct video survey of benthos and demersal fish. Targeted sampling of key benthic habitats observed in video surveys will provide the basis for the development of species inventories for macro-epibenthos through traditional sled collections.

The spatial design of the surveys include extensive coverage, at 500m spacing, of single beam cross-shelf profiles in 2007, with the goal to provide complete coverage of the park in this manner during 2008. This data will provide a broadscale coverage of the entire marine park's bathymetry and useful interpolated maps identifying areas of differing hardness and seabed texture. This data will facilitate more targeted video and collecting surveys of the major habitats in 2008, providing the opportunity to examine the variation and distinctions occurring at community level.

The research will characterise for Ningaloo the typical depth transition point between phototrophic benthos such as corals, algae and cyanobacteria containing sponges, and the deeper water filter feeding communities. The biogeographic distribution of the species will be determined for the priority taxa (dominant filter feeding species).

There are 11 specially declared sanctuary or management zones that contain water deeper than 20m. The project will assess biodiversity within and between declared deeper water sanctuary or habitat protection zones and nearby control areas of equivalent depth and latitude. Priority benthic taxa, ie either most numerically abundant or contributing greatest biomass will be identified. The remaining taxa will be held at the WA Museum and can be identified, and biogeographic distributions documented, should funding become available in the future.

Surveys of seabed biota and habitats are typically undertaken using non-destructive video sampling, usually involving a 500m long tow transect at each location (Figure 1). Additional camera tools, such as drop cameras and ROV-based transect surveys will be applied in selected locations to provide additional detail or improved taxonomic resolution. Real-time video from the seafloor is classified directly at sea using AIMS Towvid software to assign values for dominant benthos and substrate against location and depth. This provides classifications of the broad community types found at a particular location, changes in the relative abundance of the benthic biota along each transect and identifies the location of transitions in the substrate type, eg. Figures (2,3) Fish communities have been assessed in the northern half of the park using baited stereo video techniques. Further towed video and BRUVs stations will be replicated along depth contours in each survey location. To provide comprehensive spatial coverage during the course of the Project.

Once the broad patterns of bathymetry, substrate type and major habitat distributions are clarified, a comprehensive survey of the associated fish communities is planned, covering the entire marine park. This will happen in 2009 using stereo baited video systems. Video footage collected in a stereo configuration will allow accurate measurement of fish length (within 5 mm) and accurate definition of whether a fish is inside or outside a sampling unit. Baited camera tapes will be analysed using the AIMS BRUVS database and software developed specifically for BRUVS interpretation at AIMS. This will ensure quality control and the ability to compare data over temporal and spatial scales both within the marine park and more broadly in the region.

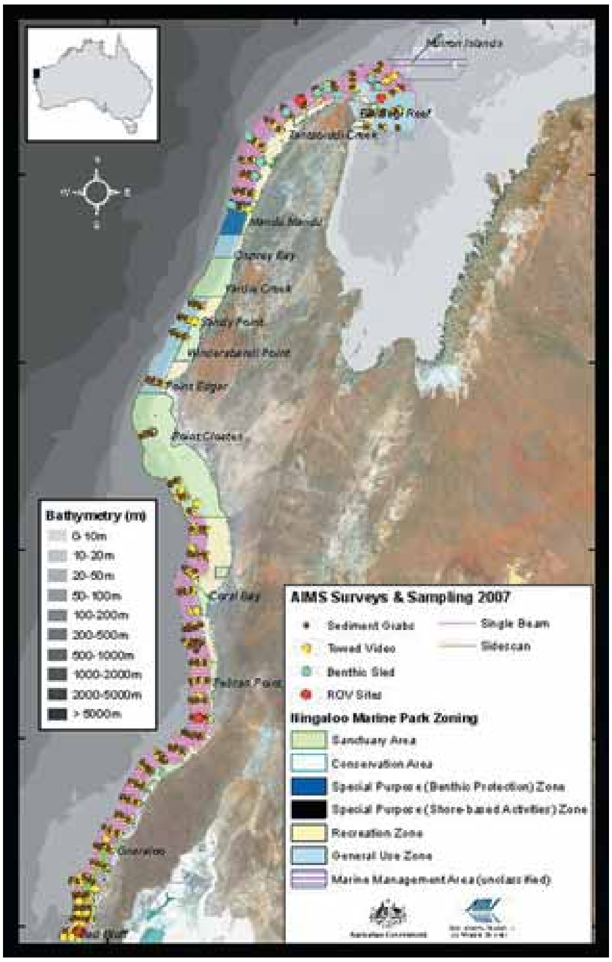

Figure 1.

Sampling coverage between 2006 and 2008 for acoustic sampling, towed video and biodiversity inventory.

Current findings and their implications for management

Surveys have been conducted in 2006, 2007 and February 2008 in the offshore areas between 30-250m, with a majority of research effort in waters less than 100m in depth.

There are several major benthic habitat types that are common along the length of the marine park. These include extensive sand areas, sometimes rippled or arranged in regular sand wave patterns in depths of 20-40m. The fore reef slope areas are frequently dominated by stony corals which appear to have reducing diversity as depth increases and become uncommon beyond 40m depth. Large fields of rodoliths frequently extend beyond the base of the fore-reef slope out to depths of around 45-50m, then across the continental shelf there are mixed sand or rubble areas interspersed with low relief rocky ridges, commonly covered with moderate to high amounts of sponge. In a few locations, notably the offshore areas of the Pt Cloates sanctuary zone, there are complex patterns of old reef-like outcrops, with many rocky knolls in the 30-60m depth zone rising up a few to almost ten meters and providing additional substrate of sponges, seafans and other benthic biota. The surveys have so far identified apparent broad-scale variation in species composition with latitude. Hard substrates are dominated by filter feeders, particularly sponges, associated with underlying geomorphology and sediments. However, in the southern end of the Ningaloo Marine Park it has been observed that even in depths as shallow as 20-30m sponges are equally as likely to dominate the habitats as are corals. In the northern end of the park, corals are much more likely to dominate such depths, suggesting some differing ecological processes are shaping the benthic communities along the length of Ningaloo

Some deepwater habitats were found to support very high biomass of sessile invertebrates, particularly sponges, but limited in spatial distribution. The focus in sampling design for 2008 will be on systematic targeted sampling of all habitat types and areas.

Video and stills were added to the sleds for sampling in 2008. This technology provides *in situ* video of the habitat sampled by the sleds and enables more quantitative estimate of sampling duration for calibration with biomass of catch. Still images will assist in the video interpretation and may ultimately provide an alternative means for quantitative analysis. Towed video stills were also introduced in 2008. These provide an in situ image, typically at 5m intervals along the transect, simultaneously while undertaking the towed video survey. Stills may be used as photo-quadrats for quantitative estimat3es of abundance and provide better taxonomic discrimination, This is an important additional set of data on the benthic communities because estimates of seabed cover by organisms from the downward-looking still camera are not subject to the complications of perspective that are associated with the forward looking tow video camera.

Acoustic surveys have been conducted in 2006, 2007 and 2008. Surveys have employed a trial of multibeam in 2006 (Fugro) and routine application of single beam (CMST) technology. All data has been processed for depth, texture and benthic classification and have been interpolated in ArcGIS to create 3D bathymetric models. The single beam coverage comprehensively covers the deepwater areas of the NMP at 500m spacing. A comparison between mulitbeam and single beam data indicate that in absolute terms the multibeam approach is superior, but the single beam data has been shown to be cost-effective and the 500m spacing useful for interpolation maps..

Fish communities were assessed in 2006 using stereo baited videos to provide size and abundance data. Over 350sp have been identified, with clear habitat associations and inshore offshore trends (see Fitzpatrick and Harvey this volume).

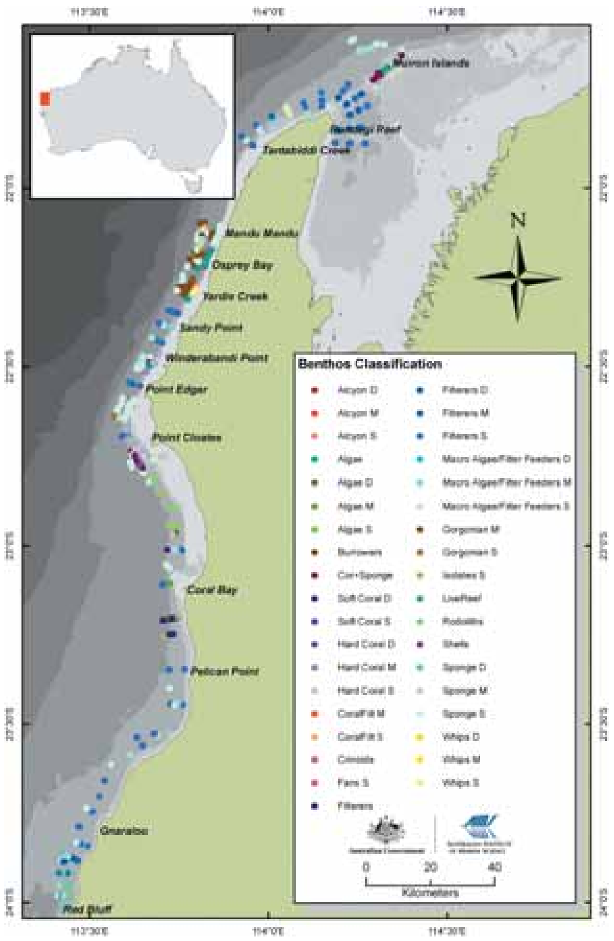

Figure 2.

Benthic surveys identified apparent broad-scale variation in species composition with latitude. Hard substrates were dominated by filter feeders, particularly sponges, associated with underlying geomorphology and sediments.

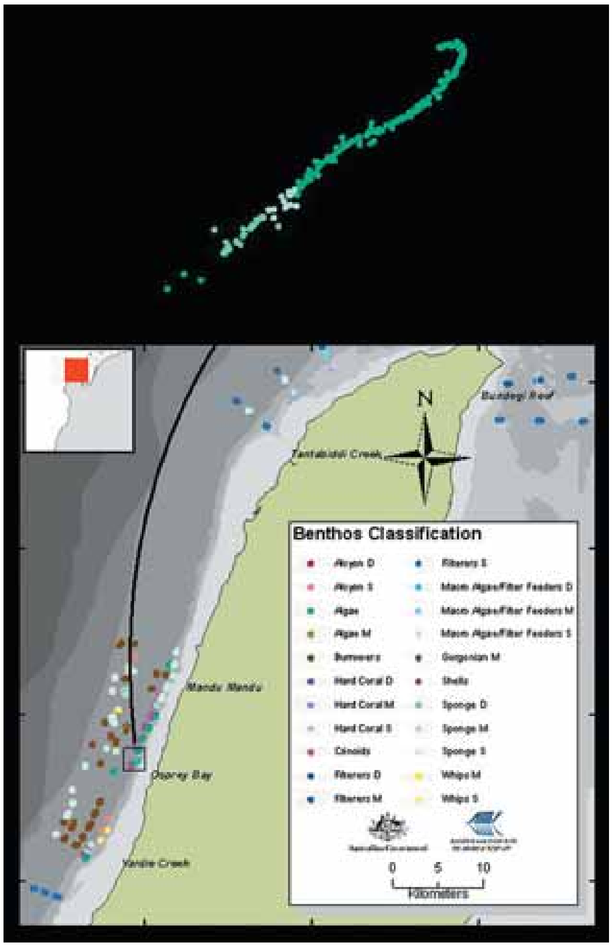

Figure 3.

Towed video data will be useful to detect transitions in benthos classification that may occur with depth or latitude.

These surveys will continue and extend the length of the Ningaloo Marine Park in 2009.

More than 300 tows have been conducted thus far These will provide qualitative descriptions of benthic habitat and will allow for quantitative analysis of both abiotic and biotic variables.

Biodiversity inventories are being established using material gathered by the benthic sleds. Sleds have been deployed in all representative habitats and have captured varying amounts of biomass. For example, biomass from a 50m sled tow ranged from 1-120kg. High biomass areas are dominated by large sponges and other filter feeders (e.g. sponge gardens). Initial observations suggest that some areas of high diversity and biomass may not be comprehensively represented in the current sanctuary zones.

Knowledge transfer

This project will provide:

- Characterisation and mapping of the dominant habitat types in deeper areas of Ningaloo Marine Park;
- Improved understanding of the biophysical domains, especially via high resolution data on cross shelf bathymetry and the distribution of sediment facies.
- a biodiversity database of dominant taxa for shelf regions at Ningaloo.

The information gathered in this study will be widely applicable to the ongoing management of the Ningaloo Marine Park. The benthic surveys will produce benthic habitat maps which can be used to assess whether current sanctuary zones are placed to adequately preserve representative habitats. Areas requiring additional mapping and research will be identified. These surveys will also produce improved bathymetry for the deep water areas of the marine park which will be used in oceanographic modeling exercises as well as in planning routine management activities within the marine park. Finally, the study will have improved immeasurably our understanding of the biodiversity that exists in these habitats and will provide a baseline from which future measurements may be compared in long term monitoring effort.

Project reports will be provided to the DEC and WAMSI, along with appropriate recommendations. Bathymetry and habitat mapping information will also be provided to the Marine Policy and Planning Branch to be used in planning activities, marine park assessments and for emergency response.

This project will produce 3D models and maps of bathymetry, geomorphology and sedimentary bedforms of the NMP All data will ultimately be lodged with WAMSI to facilitate dissemination and broader access by other users...

Figure 4.

Patches of high sponge biomass were detected in sled tows at depths of 50-100m.

Next stage

Additional field surveys of the seabed are planned in 2008, including collaborative mapping exercises that may greatly extend the coverage of the multibeam data. The existing biological material will be processed by the WA Museum to create a reference database of Ningaloo's deeper water biodiversity. Significant effort will go into analysis of the biological survey data and spatial analysis to synthesize all the major data types into an integrated report , due in mid-2009. This same analysis will provide the foundation for designing the final fish surveys in 2009.

Acknowledgements

This project is multi-disciplinary and brings together scientists and postgraduate students from Curtin University, UWA, WA Museum and AIMS. Consultation with DEC scientists and managers has been of great assistance. It has also depended heavily on the goodwill and assistance of the AIMS ships' crews and a team from Fugro Ltd for the initial multibeam.

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Monitoring reef shark movement patterns with the Ningaloo Reef Ecosystem Tracking Array

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Abstract

The movement of reef sharks at Ningaloo Reef will be tracked over the next 3 years using the Ningaloo Reef Ecosystem Tracking Array (NRETA), which is part of the nation-wide network of marine acoustic monitoring, the Australian Acoustic Tagging and Monitoring System (AATAMS). Sharks are being monitored to establish long-term patterns of habitat use and dispersal, which is essential information for effective management of populations, especially in coastal areas where sharks are particularly vulnerable to human impacts. To date 44 sharks have been tagged, 34 at Mangrove Bay and 10 at Skeleton Bay (near Coral Bay). Since November 2007 there have been 52,445 detections by receivers of the 10 sharks tagged at Skeleton Bay. To date, juvenile sharks (n=3) have only been recorded in the lagoon at Skeleton Bay, whereas adult sharks (n=7) have been recorded both in Skeleton Bay and outside the lagoon. One of the adult blacktip sharks tagged at Skeleton Bay was caught by a recreational fisher 80 km to the south outside of the marine park and another was recorded by the Mangrove Bay array (135 km to the north). These long excursions have considerable implications for population dispersal and management of reef sharks at Ningaloo. A further 100 sharks will be tagged with acoustic pingers over the next 2 years, of which 10 will be continuously tracked. This active tracking will provide fine-scale movement patterns of reef sharks, which will help confirm patterns observed with NRETA, as well as assist in determining home-ranges and habitat use.

Project description

The Ningaloo Reef Ecosystem Tracking Array (NRETA) is part of the Australian Acoustic Tagging and Monitoring System (AATAMS), a nation-wide network of marine acoustic monitoring of the movement patterns of marine animals. There are a number of tagging projects which make use of this network at Ningaloo, and these include studies of reef fish, inshore rays, manta rays and reef sharks. The reef shark tagging project started in November 2007, and so far sharks, rays and reef fishes have been tagged at Coral Bay and Mangrove Bay. Over the next 3 years, it is anticipated that over 100 sharks of a variety of species will be monitored using NRETA. The results from this project will provide a better understanding of the use of inshore habitats at Ningaloo by reef sharks, as well as identify areas of conservation importance. In particular, reef sharks form aggregations during summer months in certain locations (Mangrove Bay, Skeleton Bay, Pelican Point), which are potentially important for different phases of life cycles. For example, aggregations of adult blacktip reef sharks (*C. melanopterus*), adult grey reef sharks (*C. amblyrhynchos*), adult white tip reef sharks (*T. obesus*), and juvenile blacktip reef sharks have been observed inshore in the summer months at Ningaloo. Not only are such aggregations likely to be of importance for these populations, but they also provide an ideal opportunity to conduct tagging research, in an attempt to learn more about the population dynamics and movement patterns of these species. However, inshore reef shark aggregations are potentially vulnerable to direct impacts such as recreational fishing, as well as indirect impacts from habitat change and high numbers of marine park users during the summer. Therefore, it is hoped that the outcomes of this project will assist in the management of reef shark populations at Ningaloo Reef by not only identifying key habitats, but also by determining why sharks are abundant in inshore areas during summer months, and how they are using this habitat.

Current findings and their implications for management

For NRETA, 96 acoustic receivers have been deployed in 3 curtains and 3 arrays at Ningaloo Reef consisting of a northern curtain from the coast to the 100 m isobath slightly south of the Tantabiddi Passage, a central curtain to the 200 m isobath off Norwegian Bay, and a southern curtain to the 100 m isobath off Point Maud/Coral Bay. VR2 and VR2W receivers have been deployed on concrete filled tyres in shallow water (<25m) near the reef, while in deeper waters (>25 – 200m) VR2W and VR3 units have been deployed on moorings lines with an acoustic release anchored by 120kg steel weights. Arrays at Mangrove Bay (50 receivers), Stanley Pool (6 receivers) and Coral Bay (9 receivers) consist of VR2W units moored either using star pickets hammered into sand or concrete-filled tyres. In the initial phase of the project, 179 fishes (80 sharks and rays, and 99 coral reef fishes) were tagged at Mangrove and Coral Bays between November 2007 and June 2008. Of these tagged animals, 24 sharks and rays were tagged in Coral Bay, and 56 sharks and rays and 99 coral reef fishes were tagged in Mangrove Bay. To date, 10 grey reef sharks (*C. amblyrhynchos*), 17 blacktip reef sharks (*C. melanopterus*), 5 sicklefin lemon sharks (*N. acutidens*), 11 nervous sharks (*C. cautus*) and 1 tiger shark (*G. cuvier*) have been tagged. These were caught using a combination of hand lines, gill nets and shot-lines in inshore lagoons, except for grey reef sharks, which were predominantly caught using longlines outside the lagoon. Acoustic tags (pingers) were internally implanted in the peritoneal cavity of all sharks (Figure 1), and roto-tags were also fitted to the fins of sharks tagged at Coral Bay, to aid in future re-identification of individuals.

Since November 2007, there have been 52,445 detections by receivers of the 10 sharks tagged at Coral Bay. Juvenile sharks have only been recorded in the lagoon at Skeleton Bay, whereas adult sharks have been recorded both in Skeleton Bay and outside the lagoon. One of the adult blacktip sharks was caught by a recreational fisher 80 km to the south of Coral Bay, outside of the marine park, and another was recorded by the Mangrove Bay array (135 km to the north). These long excursions may have considerable implications for population dispersal and management of reef sharks at Ningaloo. Adult blacktip reef sharks that aggregate in inshore areas during the summer months, such as at Mangrove and Coral Bay, may be travelling long distances for reproductive or alternative purposes. These inshore areas may be vital habitats that require strict management to ensure viable populations of reef sharks at Ningaloo. Sharks leaving the Marine Park are potentially vulnerable to exploitation; therefore it is essential to determine long-term movement patterns and habitat use.

Knowledge transfer

The outcomes of this project will be particularly relevant to the management authority of the Ningaloo Marine Park, the Department of Environment and Conservation (DEC), and also any other marine park where these species occur. Furthermore, the information regarding reef shark aggregations will be of interest and benefit to interpretive and educational services provided by DEC in Coral Bay, for tourists visiting Ningaloo. It is intended that this project will also contribute valuable information to the current body of scientific literature on reef shark movement and habitat use.

The results from this study will be presented at a national resource management conference in August 2008 (Coast to Coast), as well as at the Oceania Chondrichthyan Society Conference in September 2008. In addition, findings from this project will be presented at an international scientific conference in 2009 and possibly 2010.

Figure 1.
Capture and implementation of acoustic tag.

This study has only been running for the past 6 months, therefore there have been no formal scientific publications yet, however; there will be at least 2 publications based on reef shark movement patterns at Ningaloo reef, which will be submitted during 2010 and 2011.To date, there has been a media release based on the tagged reef shark that was caught outside of the marine park, in the AIMS Waypoint Newsletter. This project will be described in the IMOS Marine Matters Newsletter in the near future. In addition, future media releases will accompany any other points of interest which come out of the study, as well as scientific publications.

Next stage

A further 100 sharks will be tagged with acoustic pingers over the next 2 years, of which 10 will be continuously tracked. This active tracking will provide fine-scale movement patterns of reef sharks, which will help confirm patterns observed with NRETA, as well as assist in determining home-ranges and habitat use. Future downloads of receivers will take place at least every six months with receivers close to the shore likely to be downloaded at a greater frequency. Receiver maintenance and downloading will be done by SIMS, AIMS, CSIRO, CDU and Murdoch University.

Acknowledgements

Shark tagging at Mangrove Bay was done in collaboration with the Commonwealth Scientific and Research Organisation (CSIRO), Charles Darwin University (CDU), Australian Institute of Marine Science (AIMS), Sydney Institute of Marine Science (SIMS), Murdoch University, and the Department of Fisheries WA, while Coral Bay tagging was done by CDU, AIMS, SIMS and Murdoch University. We thank AATAMS for providing receivers, establishing and maintaining NRETA and for managing data from the network. Funding for the tagging at Coral Bay is being provided by AIMS.

Health and hatching success of Western Australian loggerhead turtle (*Caretta caretta*) nesting populations

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Murdoch University, Western Australia

Abstract

*Most of the existing sea turtle populations worldwide are in decline. In particular, loggerhead turtles (*Caretta caretta*) are listed as endangered and loggerhead nesting populations in Eastern Australia declined by 86% since the 1970s.*

This study aims to collect critical baseline data regarding health and hatching success of the loggerhead turtle nesting population in Cape Range National Park. Adult nesting turtles were examined and a blood sample taken to establish reference ranges of several blood health parameters and screen for toxin levels. The marked nests were excavated after observed hatchling emergence to establish hatching and emergence success, and collect samples of dead hatchlings and embryos for further histological examination, as well as unhatched eggs for toxin screening. Additionally, all nests were monitored for signs of predation.

*The research was conducted for two nesting seasons (2006/07 and 2007/08) and initial results show that in Cape Range National Park nest predation is a crucial limiting factor affecting hatching success. Predation by ghost crabs (Ocypode spp), monitor lizards (*Varanus giganteus*) and feral European red foxes (*Vulpes vulpes*), considerably reduce survivorship from egg to hatchling. In fact, in the first and second years of this study 78.2% and 83.3% of the monitored nests respectively, showed signs of partial or complete nest predation. It is unlikely that this mainland nesting population can sustain such severe level of predation pressure, especially in conjunction with other anthropogenic causes of decline at foraging sites and during migration to the nesting site (i.e. poaching, fisheries by-catch and pollution), and more studies are recommended to identify successful management strategies to reduce nest predation on this beach.*

This study takes an important first step towards obtaining crucial information on loggerhead turtle nest ecology and nesting turtle health in this region.

Project description

The main objective of this study is to investigate loggerhead turtle (*Caretta caretta*) hatching success and health; two very important aspects for sea turtle conservation and management at a loggerhead nesting beach in Cape Range National Park (Bungelup beach). This project is part of a larger study focusing on health and hatching success of loggerhead turtles, which includes monitoring another important Western Australian nesting site located on Dirk Hartog Island in Shark Bay.

The research was conducted for two nesting seasons (December-March): 2006/07 and 2007/08. During the first stage, nests are marked and blood samples are collected from successfully nesting turtles. Additionally, all turtles are examined for external traumatic injuries, fibropapillomas or any other lesions.

In the second stage, nest excavations after hatchling emergence allow the assessment of hatching and emergence success, as well as the collection of unhatched eggs for toxin screening. Furthermore, all dead hatchlings and embryos are examined to identify and classify deformities, and a sub-set collected for further histological and radiological examinations. Some of the biotic and abiotic factors monitored and correlated to hatching and emergence success include: nest temperature and humidity; nest location across and along the beach; several beach characteristics; signs of nest predation; blood health parameters in nesting females and pollutant levels in undeveloped eggs and blood of nesting turtles.

An understanding of reproduction and nest biology is crucial for the recovery and management of sea turtle populations, providing fundamental data to understand the suitability of a nesting beach and the general health of the nesting population (Miller 1999). Besides, studies addressing the health of marine animals are being recognised as increasingly important due to the growing pressure on the marine ecosystem from factors, such as coastal development, pollutants and global warming (Deem 2004, Wilcox and Aguirre 2004). Loggerhead turtles are classified as endangered (IUCN 2006), and whilst the Eastern Australian genetic stock has been extensively studied since 1968, little has been published on the Western Australian genetic stock. The number of adult females breeding annually in Eastern Australia has declined by approximately 86% since the 1970s (Limpus & Limpus 2003), it is therefore considered critical to obtain baseline population data and assess the impacts of threatening processes on the Western Australian loggerhead breeding population.

In this study, special attention was given to the assessment of nest predation, as in particular nest predation by feral European red foxes (*Vulpes vulpes*) has been identified as a key threatening process in Cape Range National Park (Onton et al. 2006). Loggerhead nesting populations on the mainland of the North West Cape are significantly smaller than island nesting populations (Dirk Hartog Island in Shark Bay; Muiron Island in the Ningaloo region), and it has been speculated that ongoing nest predation by feral foxes may have contributed to the decline (Baldwin et al. 2003).

In conclusion, this study on loggerhead turtle health and hatching success will enhance general knowledge with regards to health and reproduction of loggerhead sea turtles in Western Australia; and will provide fundamental information for management policies and conservation initiatives aimed at conserving these sea turtle populations.

Current findings and their implications for management

To date, data and biological samples have been collected during two nesting seasons (2006/07 and 2007/08) and partial analyses of data has been completed.

Based on initial assessment of data, it is clear that predation by natural and introduced predators greatly reduces clutch survivorship. First results during the 2006/07 nesting season showed that nest and hatchling predation by ghost crabs (*Ocypode spp*) (Fig 1), perentie (*Varanus giganteus*) (Fig. 2) and feral European red foxes (*Vulpes vulpes*), significantly reduced survivorship from egg to hatchling. In 2006-2007, 78.2% of the monitored nests showed signs of nest predation and nests with signs of confirmed and suspected predation had a statistically significant smaller clutch size at excavation, than nests without any signs of predation (P=0.003) (Graph 1).

During the first year of monitoring, 52 nests were excavated, but clutch count at deposition was available only for 11 nests. When comparing the egg count at deposition with the count at excavation, 8 of these nests had a much smaller clutch count at excavation, due to partial predation of the nests.

Figure 1.

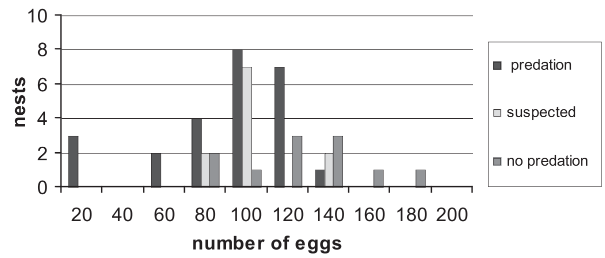
Ghost crab with loggerhead hatchling (photo by D.Mancini).

Therefore, it was concluded that, due to the high levels of predation, hatching and emergence success could not be reliably calculated from the remaining shells in the nest.

During the nesting season 2007/08, 30 study nests were marked and clutch count at deposition was available for all study nests. Additionally, all study nests were monitored every morning for signs of predation and hatchling emergence during the whole incubation period. First analyses confirm the results of the first year of monitoring, with a total of 83.3% of nests showing signs of partial or total predation. Over 60% of the monitored nests showed signs of predation by ghost crabs, while fox and perentie were responsible for 20% and 16.7%, respectively, of predations on the monitored nests (Table 1). Over half of predated nests (52%) showed signs of predation by multiple predators. The only introduced predator is the fox; however numbers of ghost crabs could have

Figure 1.

Perentie excavating a loggerhead turtle nest (photo by S.Trocini).



Graph 1.

Clutch size of nests with signs of confirmed and suspected predation, and no predation.

	% Ghost crab	Fox	Perentie	Unknown
2006/07	49.1	14.6	18.2	21.8
2007/08	66.7	20	16.7	23.3

Table 1.

Percentage of study nests with signs of predation by ghost crab, fox, perentie and unknown predator.

increased above normal levels due to tourism activities in Cape Range National Park (e.g. littering, burying of fishing offal) or possibly changes associated to climate change.

The level of predation at this mainland nesting beach can not be considered sustainable, as studies in Eastern Australian turtle populations showed that small long term increases in annual mortality from introduced sources above natural mortality levels will cause population declines. Increases in turtle mortality of more than a few percent are considered unsustainable (Limpus, 2002).

The general clinical condition of the 52 nesting turtles examined in this study was rated as good, and the screening of the blood samples collected during both nesting seasons in Cape Range National Park, in conjunction with the samples obtained on Dirk Hartog Island, will provide reference ranges for several blood health parameters (e.g. haematology, plasma biochemistry, plasma protein electrophoresis, blood vitamin levels).

Results of this study provide critical information on the nest ecology and health of loggerhead nesting turtle populations in the region and give insight on nest predation levels, as well as on predator dynamics. Important management issues are raised due to the reported high levels of predation and more studies are warranted to identify possible management strategies.

Knowledge transfer

Data collected in this study is critical to developing further understanding about nesting loggerhead sea turtle populations in the Exmouth region and to making informed decisions with regards to prioritising management actions. Therefore information gained from this study will be useful for both the scientific community and the Western Australian Department of Environment and Conservation. Preliminary results have been presented at national and international conferences (International Sea Turtle Symposium, Wildlife Disease Association conference; Wildlife Disease Symposium at Perth zoo) and other results obtained from further data analyses and laboratory work will be presented at several other conferences on wildlife health and management. Additionally, all results will be submitted for publication in relevant peer-reviewed journals. By the end of the study all results will be presented to the Department of Environment and Conservation in Exmouth, so that information gained during this project can be utilized to develop recommended guidelines and define management priorities to facilitate high levels of hatching success.

Next stage

Further statistical and laboratory analyses on the 2007/08 nesting seasons are underway. It is expected that necropsies and histopathological examinations of tissue samples of dead embryos and hatchlings collected during both nesting seasons will be completed by May 2009.

Several management strategies to reduce nest predation will be recommended and the success of such strategies could be assessed by experimental studies. Additionally, further investigations might be warranted in the future to assess the success of the ongoing fox baiting program and to investigate if ghost crab numbers are artificially increased due to anthropogenic factors (e.g. fishing offal buried near to fishing sites may increase crab numbers due to a constant and reliable food source).

Acknowledgements

I would like to gratefully acknowledge Dr Alan Kendrick, Roland Mau, Kim Onton, Brooke Halkyard and Cath Samson and all staff from the Department of Environment and Conservation Exmouth district for their ongoing support; Dr Bob Prince for advice; all my volunteers, for their invaluable help and endurance during the long hours of field data collection; all the Ningaloo Turtle Programme volunteers that helped out during the past nesting season, particularly John Stuart; and VetPath and the Chemistry Centre for their collaboration in this project. Funding for this study has been provided by BHP-Billiton, DEC, The Hermon Slade Foundation and Murdoch University.

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Ningaloo Marine Park Drupella long-term monitoring program

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Abstract

Between the mid 1980s and early 1990s, the feeding activity of unusually high densities of the corallivorous gastropod Drupella cornus *resulted in massive coral damage along at least 100 km of Ningaloo Marine Park (NMP), with coral mortality approaching 100% at some areas. The density of* D. cornus*, the area and severity of associated coral damage and longevity of the outbreak itself that occurred at NMP during this event was on a greater scale than recorded on other reefs elsewhere in the world to date.*

As the health of coral communities is a key performance indicator of management of NMP and the Muiron Islands Marine Management Area (MIMMA), it is essential to keep a watching brief on spatial and temporal changes to D. cornus densities and cover of associated corals in these conservation reserves. Adhering to this management need, the aim of the Ningaloo Marine Park Drupella Long-term Monitoring Program (NMPDMP) is to monitor long-term changes in the density of D. cornus and cover of associated coral communities at the NMP and the MIMMA. Monitoring of D. cornus *at NMP has produced a long-term data set with information describing the status of* D. cornus *populations and coral communities dating back to 1987.*

The results of the surveys indicate that, relative to the outbreak densities recorded during the late 1980s and early 1990s, D. cornus *densities have been low to moderate since 1994 and have not greatly affected coral cover at the NMP and MIMMA. Coral cover has generally increased since 1994.*

A strategy in the revised NMP and MIMMA Management Plan 2005-2015 requires that D. cornus *abundance and the health of coral communities be surveyed at least every three years. The last major survey was conducted in April 2008.*

Project description

Large numbers of *D. cornus* were first observed at Ningaloo Reef in 1982 and later confirmed in 1985. In early 1987, large numbers of *D. cornus* were observed consuming hard corals at several locations along the then proposed NMP during a survey initiated by the Department of Conservation and Land Management [1] (CALM). In 1989, six long-term *Drupella* monitoring locations were established and surveyed by CALM. In 1991, these six locations were re-surveyed and seven new long-term *Drupella* monitoring locations were established by CALM. In 1994, all thirteen locations were re-surveyed by CALM. In 2005, an improved method for monitoring *Drupella* was developed using precision and cost benefit analyses and the thirteen locations were re-surveyed using the new method. Effort was made to ensure statistical comparability between the results generated by the old and new methods. The work in 2005 was undertaken by an honours student and funded by CALM. In 2006, four of the thirteen locations were re-surveyed and six new *Drupella* long-term monitoring locations were established to represent the southern extension of the NMP and the gazettal of the MIMMA. As of 2006, the study has been led by the DEC's Marine Science Program (MSP). There are now nineteen *Drupella* long-term monitoring locations, positioned approximately every 20 km along the NMP (Figure 1).

The study uses a nested survey design with three replicate sites per location and three randomly positioned 20 m transects per site. Along each transect *Drupella* density is estimated by visual search and benthic community cover is recorded using underwater video.

Current findings and their implications for management

Present *Drupella* densities are low to moderate compared to the outbreak densities observed during the late 1980s and early 1990s, and represent no immediate threat to coral communities at NMP. Coral communities appear to have recovered from the *Drupella* outbreak event in the 1980s, with live hard coral cover increasing consistently since 1994 at most locations. DEC will continue to keep a watching brief on *Drupella* and coral communities at NMP, by undertaking surveys at least every three years as outlined in the NMP and MIMMA Management Plan. In the meantime any anecdotal information regarding changes in localized densities of *Drupella* should be reported to DEC's MSP.

Issue 1: Mechanical damage to corals may attract *Drupella*

Although the reasons for 'outbreaks' in Drupella densities remain unclear, it is important to try, if possible, to mitigate any potential anthropogenic causes of increased numbers of

1 On the 1st of July 2006, the Department of Conservation and Land Management and the Department of Environment amalgamated and renamed the Department of Environment and Conservation (DEC).

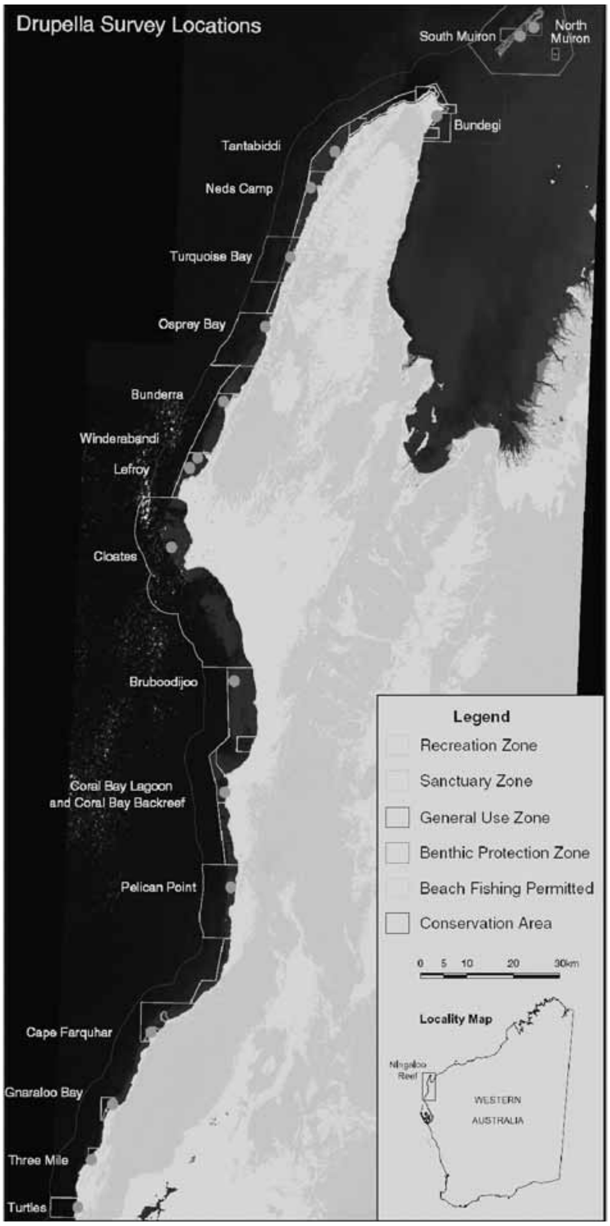

Figure 1.

Position of the Drupella long-term monitoring locations at NMP and MIMMA.

Drupella. Research has shown that mucus produced by damaged coral (e.g. anchor damage, inexperienced diver damage) is a feeding stimulus for Drupella. Qualitative observations from a heavily visited dive and snorkel site named Asho's Gap at Coral Bay suggest that D. cornus feeding aggregations are being attracted to broken coral, most likely caused by inexperienced divers or boaters. Continuing coral damage during such activities could attract increased numbers of D. cornus to this site causing local declines in live coral cover resulting in a reduction in the attractiveness of the site for diving and snorkelling.

Management Recommendation 1: A simple education pamphlet should be developed and distributed by Exmouth District as soon as possible to encourage more sustainable diving and boating practices to address this issue.

Knowledge transfer

Knowledge gained from the survey will be used to improve policy, planning and management by providing an update on the information concerning the status of D. cornus populations and cover of live coral at NMP and the MIMMA. The data from this project will be used as a measure of the condition of coral reef communities (KPI) of the reserves.

The project has produced numerous outputs including a data and technical report, popular magazine articles, newspaper articles, radio interviews and broadcasts and presentations at national conferences.

Next stage

Statistical analysis of the 2008 data is in the process of completion. The 2008 component of the study will generate several outputs including a data report, a technical report and scientific paper.

Acknowledgements

The project is funded by DEC and led by DEC's MSP with operational support from DEC's Exmouth District. Data collected by Sue Osborne and Jim Stoddart in the 1980s and 1990s contributed to the long-term data set. Assistance in the field by various DEC MSP and Pilbara Region Staff was greatly appreciated.

Coral Bay reef recovery study

Shannon Armstrong [1], **Dr Suzanne Long** [1], **Dr Luke Smith** [2], **Dr Chris Simpson** [1],

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Abstract

Understanding of the conditions that promote recovery and resilience is essential for future effective management of the world's increasingly disturbed coral reefs, and this understanding requires long-term studies of reef responses to disturbance. We used robust non-parametric statistical analyses to describe the responses of reefs in Bill's Bay (Ningaloo Reef, Western Australia) to acute non-destructive disturbances over a 17-year period. Reefs in inner Bill's Bay were completely killed by a dystrophic crisis in 1989: unusually calm wind and sea conditions coinciding with mass coral spawning caused the accumulation of coral spawn in the bay and the respiratory demand of the spawn slick followed by its in situ decomposition depleted available oxygen in the water column and sediments.

Recovery of pre-disturbance levels of coral cover from this zero baseline occurred within 10 years, and recovery of pre-disturbance type acroporid-dominated coral communities was achieved at one site within 17 years. As has been reported elsewhere in the Indian Ocean, recovery commenced through recruitment and growth of non-acroporid taxa (faviids). Our analyses of coral reef recovery patterns following this kind of disturbance, in which the reef matrix is not damaged, are likely to be relevant to coral recovery patterns following other acute non-destructive disturbances, such as the increasingly common global phenomenon of catastrophic bleaching.

In March/April 2008 another dystrophic crisis occurred in inner Bill's Bay that appears to have been the most severe in terms of area of coral mortality to occur since 1989. Observations suggest that approximately 30 to 60% of existing corals were bleached and bleaching occurred across most coral species. Results of a recent survey will indicate the extent of morality and/or recovery.

In stark contrast to most Indo-Pacific reefs, those in the outer zone of Bill's Bay, Ningaloo Reef, appear to have been remarkably stable over the past 17 years in terms of coral cover and high-level coral community composition. If they continue to be relatively unimpacted by, and/or resilient to, environmental disturbances and human activities, these stable outer zone reefs at Ningaloo, and others like them in Western Australia, may be able to serve a critical function as coral reef refugia and reference sites of local, regional and potentially global significance.

Project description (and background)

Since establishment of the baseline in 1989 by the Environmental Protection Authority (EPA), the coral reef communities of Bill's Bay have been resurveyed in 1994 by the EPA, in 1995/96 by the Australian Institute of Marine Science (AIMS), in 2000 by the Department of Conservation and Land Management (CALM), in 2001 by AIMS, in 2004 by AIMS and in 2006 and 2008 by the Department of Environment and Conservation's Marine Science Program and Pilbara Region.

Several changes in survey method occurred over the 17-year period. Therefore a cautious approach was taken in analysis of the data to ensure valid interpretation. See Long and Simpson (this volume) for a description of analyses used to determine similarity between the various survey methods.

At each site, DEC surveys three 50 m transects, 20 m apart, positioned parallel in an east-west orientation. Benthic community composition is recorded using underwater video transect techniques. Video data is analysed using the AVTAS method. The results are comparable with data collected in Bill's Bay in previous years by both DEC and AIMS.

Current findings and their implications for management

The following results include data up to 2006. The 2008 data are currently being analysed.

Stability

In stark contrast to most Indian Ocean reefs, those in the outer zone of Bill's Bay appear to have been remarkably stable over time in terms of coral cover (Fig 2), high-level coral community composition, and rates and taxonomic composition of sexual recruitment. If these back reef habitats continue to be relatively unimpacted by, and resilient to, environmental disturbances and human activities, these stable outer zone reefs at Ningaloo, and others like them in Western Australia, may be able to serve

1 On the 1st of July 2006, the Department of Conservation and Land Management and the Department of Environment amalgamated and renamed the Department of Environment and Conservation (DEC).

Figure 1.

The three 50 m transects surveyed at each of the 17 sites in Bill's Bay in 2006 and 2008 by DEC.

a critical function as coral reef refugia and reference sites of local, regional and potentially international significance.

Recovery

Reefs in inner Bill's Bay were completely killed by the 1989 dystrophic crisis. Recovery of pre-disturbance levels of coral cover from this zero baseline occurred within 10 years (Fig 2), and recovery of pre-disturbance type acroporid-dominated coral communities was achieved at one site within 17 years (although most recovering inner zone reefs had not yet reached this successional stage at the time of the latest survey). If these reefs are not disturbed, continuing patterns of ecological succession are likely to result in recovery of mature coral communities in the inner zone of Bill's Bay. The implication is that areas of Ningaloo Reef may be capable of recovering from acute small-scale disturbances, although full recovery may require more than 20 years.

Vulnerability

Although recovery processes appear to be underway at some reefs in the middle zone of Bill's Bay, the apparent lack of recovery observed at some sites in recent surveys (2000, 2006) leads to concerns that these reefs may be vulnerable to degradation of resilience. The likely cause of this potential loss of resilience is the increased frequency and/or intensity of disturbance in this zone. Chronic disturbance of coral reefs elsewhere has been linked to loss of resilience and sudden shifts from coral- to algal-dominated communities, with concomitant dramatic reductions in biodiversity and

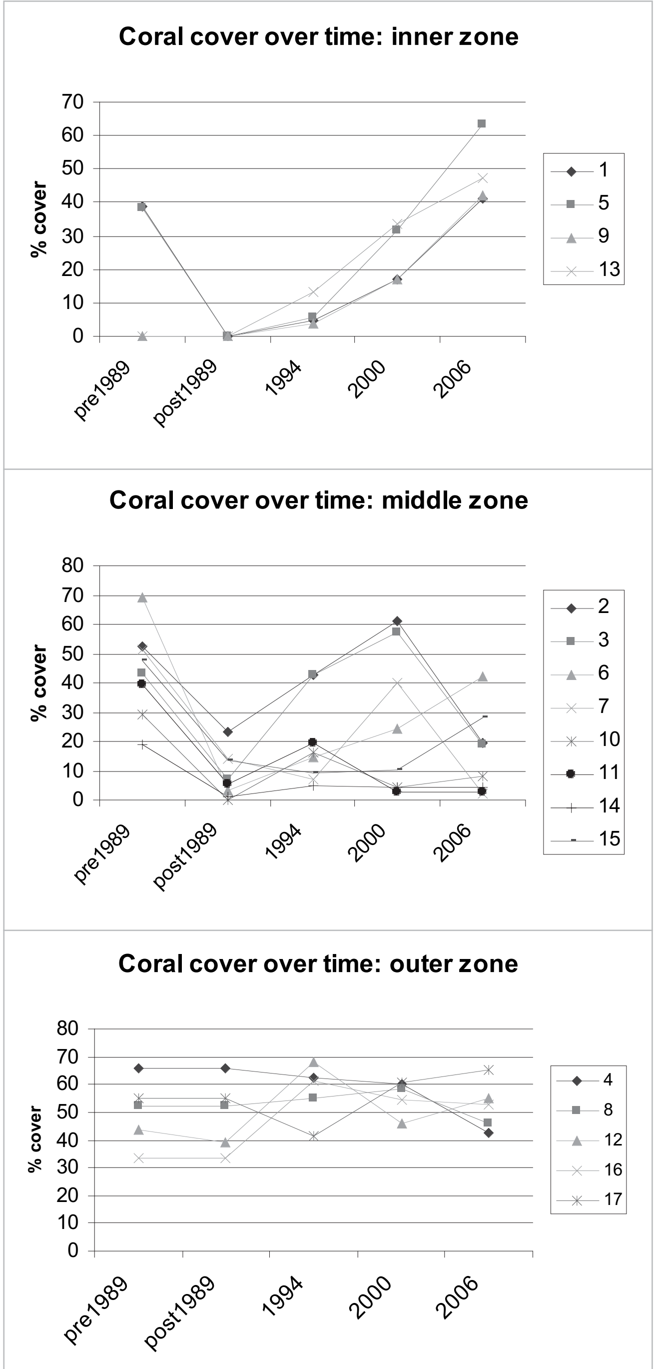

Figure 2.

Mean live coral cover over time for each site in each zone in Bill's Bay.

productivity (in terms of ecosystem goods and services). Careful, informed management will be required to minimise disturbance and foster resilience of these vulnerable reefs in Bill's Bay.

Recommendations for management

- Minimisation of human-derived disturbances to coral reef communities in Bill's Bay and elsewhere at Ningaloo Reef. Consultation with the Marine Science Program of DEC before licensing/permitting activities that could affect coral reef ecological processes, even on a very localised scale.
- Annual scientific monitoring and reporting of coral spawning events in Bill's Bay, and documentation and reporting of the extent and severity of spawning-related dystrophic crises when they occur.
- Increasing levels of protection for the resilient reef at site 1 (the closest site to shore and town; Figure 1) by installation of an informative public snorkeling trail. In addition to increasing visitors' understanding and appreciation of the natural environment in Coral Bay, this will minimise human impacts on this reef by containing most visitors to the vicinity of the trail, educating them about safe snorkeling practices, and preventing boat access to the area.
- Scientific investigation of the apparently increasing size of the sand spit at Coral Bay, to determine whether human activities are contributing to this process. Changes in sand and water circulation patterns are likely to impact on coral communities in the vicinity and may have long-term ramifications for the health of local coral reefs.

Knowledge transfer

This project has and will continue to inform management of the health of coral communities, a key performance indicator of management, at this very popular and heavily visited area of the Ningaloo Marine Park. It will also provide timely scientific insights into the long-term capacity of central Ningaloo Marine Park coral reef communities to recover from disturbance.

Next stage

The next stage of this project is to complete the analysis of the 2008 data and prepare a data report and technical report. This will be followed by finalising the existing data report that documents the 2008 anoxic bleaching event. Coral communities at Bill's Bay will be monitored by DEC at least every three years as highlighted in the Management Plan for the Ningaloo Marine Park and Muiron Islands Marine Management Area (2005 - 2015).

Acknowledgements

This project is funded by DEC's Marine Science Program (MSP) and Pilbara Region. Data from AIMS and EPA was used in the analyses. The work presented in this report was undertaken by Dr Suzanne Long, DEC MSP; Dr Luke Smith, AIMS, and Dr Chris Simpson, DEC MSP (Long, Smith & Simpson, in prep).

Satellite Tracking of Loggerhead Turtles (*Caretta caretta*) at Ningaloo Marine Park

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Abstract

*The beaches of the Ningaloo coast form part of critical nesting habitat for the West coast population of the nationally endangered loggerhead turtle (*Caretta caretta*). Most research conducted on marine turtles has been carried out on nesting beaches while well over 90% of a turtle's life is spent in the water – feeding, resting, mating, migrating etc. This leaves us with very limited knowledge about conservation needs of marine turtles while at sea. A greater understanding and knowledge of marine turtle habitat use and migratory paths and patterns is becoming increasingly more critical with growth in tourism, aquaculture, and oil and gas exploration and coastal and regional marine conservation reserve planning processes along the North-West shelf. This project aims to gain an understanding of habitat use and migratory paths of breeding* Caretta caretta *marine turtle species from Ningaloo Marine Park. The objectives of the project were: to establish migratory and behavioural patterns for breeding* Caretta caretta *marine turtles; to establish migratory routes and foraging habitats; and to establish use patterns of these different habitats. Nine loggerhead turtles were fitted with KiwiSat Platform Terminal Transmitters (PTTs) following a nesting emergence in the months of December 2007 and January 2008. All PTTs were successfully deployed and four were still transmitting by August 2008. All turtles appeared to have settled into feeding areas at the time of last transmission. The tracked turtles migrated to areas near Shark Bay, 80 Mile Beach, One Arm Point, Timor Sea, Torres Straits and one remained at Ningaloo reef.*

Project description

The loggerhead turtle has been listed as a threatened species under the *WA Wildlife Conservation Act 1950* and identified as endangered under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*. Western Australia supports one genetic stock of loggerhead turtles with nesting encompassing the Shark Bay to North-Western region including the Ningaloo coast (Baldwin *et al.*, 2003).

Even though WA supports one of the largest nesting populations of loggerhead turtles in the world, this stock is exposed to substantial unquantified losses from a broad range of anthropogenic activities (Limpus, 2002).

The 2003 "Recovery Plan for Australia" (Commonwealth) identified steps necessary to reduce threats on marine turtles to allow for the national recovery of all marine turtles. Specific objectives of the plan include "*to identify and protect habitats that are critical for the survival of marine turtles*" (p.10; item C). Habitats were categorised as: natal beach, mating, inter-nesting, feeding and pelagic.

Little is known about feeding habitats of loggerhead turtles at Ningaloo Marine Park (Carter, unpublished). In a review of loggerhead populations in the Indian Ocean, Baldwin *et al*. (2003) identified, amongst others the following management related research needs:

- benchmark aquatic habitats and feeding grounds; and
- more detailed information on dispersal from nesting beaches and on migration routes.

A greater understanding and knowledge of marine turtle habitat use and migratory paths and patterns is becoming increasingly more critical with growth in tourism within the reserves and oil exploration just outside its boundaries. The current development of a Visitor Services Plan for Ningaloo Marine Park will require considerable knowledge of all marine habitats used by marine turtles in the reserve to ensure that incompatible activities are not focused into significant marine turtle habitats and conflicting uses can be separated.

Research into the behaviour and life cycle of marine turtles has taught us that these creatures do not generally nest and feed in the same area. We now know that marine turtles are highly migratory, often travelling hundreds of even thousands of kilometres between the beaches where they lay their eggs and the foraging (feeding) grounds where they spend much of their time at sea (http://www.cccturtle.org/satellitetracking.php?page=satintro).

Most research conducted on marine turtles has been carried out on nesting beaches while well over 90% of a turtle's life is spent in the water – feeding, resting, mating, migrating etc. This leaves us with very limited knowledge about conservation needs of marine turtles while at sea. For instance, Zbinden *et al.* (2007) used satellite telemetry data to assess the efficacy of two zones of marine reserves (i.e. boat exclusion areas) in relation to internesting area use of four loggerhead turtles nesting in the Bay of Laganas (Zakynthos, Greece). Hawkes *et al.* (2006) used satellite tracking to investigate the migratory movements of adult female loggerhead marine turtles from one of the world's largest nesting aggregations at Cape Verde, West Africa, and found that adults displayed two distinct foraging strategies that appear to be linked to body size. The conservation findings of this were profound, with the population compartmentalized into habitats that may be differently impacted by fishery threats.

The technology of satellite telemetry has become useful and important in protecting marine turtles and their habitats. Satellite telemetry provides the means to monitor the movement and behavioural patterns of multiple turtles for a year or more at great distances (Eckert 1999). Satellite telemetry (following an object on the earth with the use of orbiting satellites) has advanced to the stage of allowing researchers to track turtles in the open ocean after attaching a Platform Terminal Transmitter (PTT) to the back of a marine turtle.

This project aims to gain an understanding of habitat use and migratory paths of breeding Caretta caretta marine turtle species from Ningaloo Marine Park and beyond. The objectives of the project were:

1. to establish migratory and behavioural patterns for breeding *Caretta caretta* marine turtles;
2. to establish migratory routes and foraging habitats;
3. to establish use patterns of these different habitats;

Current findings and their implications for management

The PTTs for this project were programmed for a 24 hours/day transmission with a 40 second repetition rate. The KiwiSat PTT should thus operate for 245 days continuously, however, the salt water switch will turn the PTT off when underwater and save power so the actual life will be in excess of a year.

Nine KiwiSat 101 PTT were applied to the carapace of female *Caretta caretta* following their nesting emergence on a beach in Cape Range National Park between 17 December 2008 and 24 January 2008. Details of their morphology are provided in Table 1 below. All turtles were flipper tagged under DEC's Western Australian Marine Turtle Program. A general health and condition assessment was made of individual turtles prior to the attachment of the PTT using an industrial epoxy glue, Powerfast®. Three loggerhead turtles were deemed unsuitable due to either heavy barnacle loading at the preferred attachment site or due to injury.

Knowledge transfer

The knowledge gained from this project will be provided to government agencies and marine resource managers primarily in form of a technical report and GIS data layer with metadata.

The project itself is hosted on seaturtle.org and any fellow marine turtle researcher can access the project outline and basic track maps. Further knowledge may be developed by researchers seeking to investigate the foraging grounds identified.

This project involved local community members in the application of the satellite tags to foster greater stewardship for the needs of marine turtles found along the Ningaloo coast.

Publicity has already been generated through two separate press releases, one at the local level and a second through Perth. The media releases led to on feature on WIN News, two radio interviews (ABC Regional and ABC Perth), an article in the West Australian, the regional paper, and two local papers.

The information gained has been relayed to relevant researchers and managers at a Workshop for remote area scientists and managers attended by the Principal Investigator. The follow up lead to contacts with Geoscience Australia and CSIRO in regards to Commonwealth Regional Planning for the North-West shelf.

Satellite tracking information is made publicly available to all interested stakeholders on www.seaturtle.org and the Ningaloo Turtle Program website www.ningalooturtles.org. A link to the website has also been provided to the DEC Marine Policy and Planning Branch to be considered as part of the development of new marine protected areas off the Pilbara coast.

Next stage

As the PTT are still transmitting, the analysis of the data will commence once the last transmission has ceased and no

Table 1.

Details of PTT KiwiSat101 PTTs deployment at Cape Range, Ningaloo Marine Park

No.	PTT ID no.	Turtle name	CCL (cm)	CC Width (cm)	Date of deployment	Transmission (days)	Distance travelled (km)	Straight line distance	Reference to nearest known location(s)
1	76031	Kate	96.5	81.5	11/01/2007	111	99	51	Jurabi Point, North-West Cape
2	76032	Susie	89.8	76.7	12/01/2008	57	1282	1097	Lacepede Island
3	76033	Lindsay	92.0	83.6	12/01/2008	221	4076	1616	150km east of Ashmore Reef
4	76034	Nicki	96.7	88.1	24/01/2008	203	3509	3203	100km north-east Cape York
5	76035	Claire	97.5	84.1	12/01/2008	213	447	431	South-eastern end of Dirk Hartog Is
6	76036	Jacqueline	94.5	85.5	19/01/2008	133	934	833	Northern end of 80 Mile beach
7	76037	Brooke	104.0	90.5	17/12/2007	242	1295	373	Cape Peron, Shark Bay
8	76038	Jen	97.5	85.0	19/01/2008	154	2903	2085	Timor Sea, 200km off Bathurst Is
9	76039	Naysa	97.8	87.5	21/12/2007	176	1135	682	Cape Keraudren, 80 Mile beach

Figure 1.

Map depicting the migratory routes and current locations of the nine tracked Caretta caretta *(as of 19/08/08)*

further signals are recorded for a period of two months. Due to fouling of the salt water switch by algae and subsequent removal during foraging behaviour, several PTTs had ceased transmitting only to become active again after several weeks. A project report will be prepared and distributed to funding providers. It is anticipated that a manuscript will be prepared for presentation at the International Turtle Symposium in Brisbane (February 2009) and scientific publication.

Little is known about the offshore habitats off the North-west shelf that appear to make up foraging grounds of the female loggerheads. Spatial information about the foraging grounds will provide researchers with areas to target for future habitat assessments.

When comparing this dataset with other tagging projects, some marine turtle foraging area hotspots may be identified. For instance, there are now three different species of marine turtles (*Natator depressor*, *Chelonia mydas* and *Caretta caretta*) that appear to favour an area off Roebuck Bay and to the north-east of 80 Mile beach.

The Commonwealth Department of Environment, Heritage, Water and the Arts is currently in Regional Marine Planning process and are seeking data indicating critical habitats that may require some form of management control.

There are numerous offshore gas and oil projects under investigation on the North-West shelf, Timor Sea and Gulf of Bonaparte. An understanding of habitat and migratory routes of *Caretta caretta* will allow decision-makers to consider their needs in relation to an expanding resource industry.

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- Commonwealth Department of Environment, Heritage, Water and the Arts
- Kevin Lay, Sirtrack Ltd

References

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Review of the Ningaloo Marine Park whale shark (*Rhincodon typus*) tourism interaction industry monitoring data from 1996 to 2008

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Abstract

The Department of Environment and Conservation (DEC) through the whale shark tourism industry have been collecting industry and ecology-related data since 1995. This project aimed to review the monitoring data to determine industry trends and whale shark ecology for the Ningaloo Marine Park aggregations. In 2002, a review of data from 1995-2001 led to modifications to the logbook datasheet, expansion of data collection period to encompass all vessel and whale shark interactions, and the addition of aerial spotter plane data from 2002 onwards. Paying passenger numbers increased by 270% from 1996 to 2007 with nearly 7000 participants in the 2007 season joining one of the record 424 tours conducted. The increase in participants has led to an increase in passenger numbers per tour from 10.6 to 16.5. The statutory interaction Code of Conduct restricts swimmers per sharks at any one time to a maximum of 10. The average number of swimmers per contact has not changed significantly from 7.5 to 7.8 but, as more time is required to ensure everyone gets a good swim, the average tour time has increased by about 1 hour 30 minutes. The interpretation of whale shark ecology data from the logbook required more considerate analysis as this data was not collected in a scientifically rigorous manner and the sampling period was restricted to the peak tourist season until 2005. Augmentation of the vessel logbook data for all interactions as well as with spotter plane data improved data utility and has yielded interesting trends related to intra-seasonal variation in whale shark abundance. A manuscript is in preparation.

Project description

In Western Australian waters the whale shark (Rhincodon typus) is fully protected and listed as a threatened species under Western Australian State legislation and declared to be "vulnerable" under Australian Commonwealth legislation. Internationally, the conservation status of the whale shark is unclear and listed as having an "indeterminate" status in the World Conservation Union Red List of Threatened Species.

The Department of Environment and Conservation (DEC) is the statutory body in Western Australia responsible for the management of whale shark interaction tourism in the Ningaloo Marine Park under the Wildlife Conservation Act 1950. Whale sharks are seasonally present in this marine reserve and these animals have become the focal point for a tourism industry that provides in water experiences with whale sharks. DEC has developed a whale shark management program to monitor and manage human interaction with whale sharks and the industry that provides these experiences. It is a primary imperative in the management of the whale shark interaction program that any impacts on the health of individuals and the overall population are identified so that an adaptive management regime can be applied.

This project aims to review the existing whale shark industry logbook data to evaluate its utility in determining industry trends and ecological parameters of whale sharks in the Ningaloo Marine Park. In particular, there is a need for careful consideration of assumptions and data accuracy to ensure that scientific rigour and outcomes are not compromised. This is critical as the industry logbook data is provided to scientists and is used in support of scientific research including several recently published studies on whale shark abundance (e.g. Bradshaw et al, 2008; Sleeman et al in press). The objectives of the project are:

- to ensure ecological data collected through the whale shark interaction industry has scientific applications; and
- to determine sources of error within the existing vessel logbook data set so that data accuracy and interpretation may be improved in the future.

Since 1995, each licenced tour operator has been required to record every whale shark interaction conducted throughout a season in vessel logbooks, as per licence conditions. This includes length of tour, passenger numbers, GPS locations of sharks interacted with, size, sex, time of sighting, direction of travel, response to swimmers, number of swimmers and length of contact per each group.

However modifications were made to the logbook datasheets in 1996, which has meant that the 1995 data set is often not included in analyses due to inconsistency in data collection. In 2002 the logbook data was reviewed and again (Chapman, 2002), the datasheet was modified. Key changes included:

- provision of five behavioural response codes so that operators could consistently record the main responses of whalesharks to swimmers;

- contact information was expanded and divided into number of swimmers and length of contact per group to allow operators to provide more detail on each interaction;
- a ‘handballing’ section was also included to allow DEC to determine if one shark was being shared between vessels or whether multiple sharks were present; and
- a diagram used to record any scarring/identifying features was removed due to operator subjectivity.

It also became apparent that data was only collected during the peak tourist season in April and May whereas whale sharks were known to be present from March to July. Further effort was put into enforcing compliance with the license conditions relating to the collection of logbook data over the entire season from 2005 onwards to improve data collection throughout the whaleshark season.

Spotter pilot data was also introduced in 2002. Spotter planes are required to locate whale sharks for the tourist vessels and they maintain records on flight time, pathways and number and location of whale sharks sighted. This information is recorded on a daily basis throughout the season (Mar-May) and has been available since 2002.

As described above, there have been several changes over time to this long term data set that could have implications for its usefulness when looking for long term trends. In particular, the dataset from 1995 is often not used as it contains limited information. The addition of spotter planes also adds a new data element that must be assessed to understand the relevant assumptions between survey effort and abundance measures.

Current findings and their implications for management

Industry

Paying passenger numbers increased by 270% from 1996 to 2007 with nearly 7000 participants in the 2007 season joining one of the record 424 tours conducted. The increase in participants has led to an increase in passenger numbers per tour from 10.6 to 16.5. The statutory interaction Code of Conduct restricts swimmers per sharks at anyone time to a maximum of 10. The average number of swimmers per contact has not changed significantly from 7.5 to 7.8 but as more time is required to ensure everyone gets a good swim, the average tour time has increased by about 1 hour 30 minutes.

Based on paying season logbook data (April and May only), the relative number of whale shark interactions was lower by 36% in 2007 compared to 1996. However, the whale shark interaction success rate (i.e. the number of charter trips with whale shark interactions to those without) has not significantly changed over this time with a mean across all years of 80%.

Methodology

The DEC’s Whale Shark Management Program (Coleman, 1997) identified the need for spotter plane search effort records to augment the operator logbooks to derive scientifically rigorous data required for relative abundance monitoring.

Several publications have been written that discuss relative whale shark abundance, size, size class distribution and environmental influences affecting their relative abundance at Ningaloo. These papers have relied upon the data from tour operator logbooks to support hypotheses of reduced relative abundance of whale sharks, smaller sharks and changed frequency distribution and the effects of ENSO events on relative abundance at Ningaloo.

These studies have used the actual interacting vessel time as a surrogate for search effort (Wilson et.al., 2001; Bradshaw et.al, 2007; Bradshaw et.al., 2008; and Sleeman et. al, in press). However, there is some discrepancy over whether the vessel time can be used as a surrogate of search effort. This study hopes to clarify the issue and the relevant assumptions that will need to be taken into consideration in the analysis of both logbook and spotter plane data.

Temporal distribution

Early publications (Taylor, 1996, Wilson et. al. 2001) suggested that the highest abundance of whale sharks at Ningaloo occurred in the months of April and May each season. The whale shark paying season was established for April and May and consequently extensive operator logbook records were only maintained for these two months. Following the review of the logbook data (2002) it was apparent that the number of logbook records were influenced significantly by passenger participation levels rather than whale shark availability.

The research team found significant aggregations of whale sharks into July (personal observation) and began to collect spotter plane search effort data for all whale shark sightings. It became apparent that whale shark abundance was greater outside the perceived “peak” season than within for all but one of the six years (Figure 1). The data for this project will be analysed to determine the extent of intra-annual variation of relative whale shark abundance. If this change is significant the implications of this variance will need to be considered in population models to improve their predictability of changes in relative abundance of whale sharks at Ningaloo Marine Park.

Size distribution

Recent publications based on whale shark industry logbook data (Mau & Wilson, 2007; Bradshaw et al 2008) suggested an overall decrease in mean whale shark size from 1996-2004 at Ningaloo. Updated estimated length data showed that mean size had decreased from about 7 to 5.5 metres from 1996 to 2002, with no apparent change in mean length from

Figure 1.

Comparison of search effort between full and paying season spotter pilot data between 2002 - 2007.

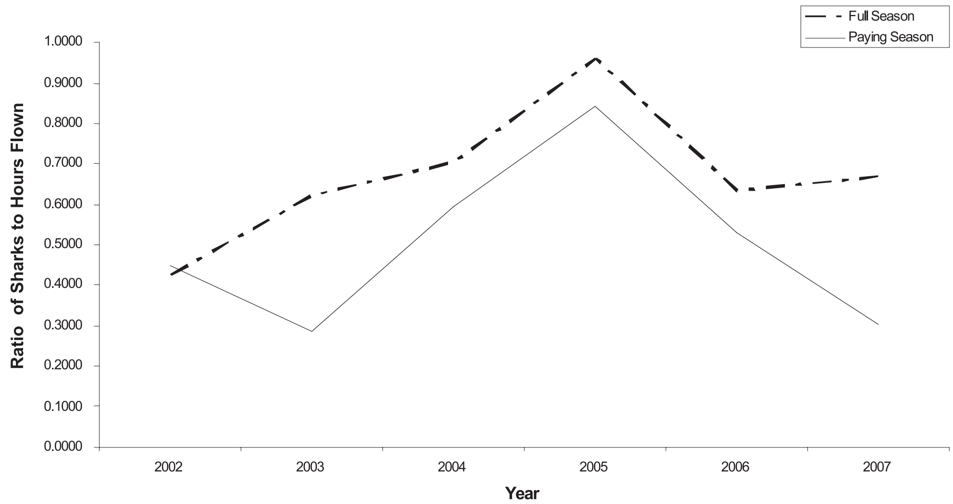

Figure 2.

Average paying season industry estimated whale shark length with standard deviation from 1996 to 2007 (n=5,978)

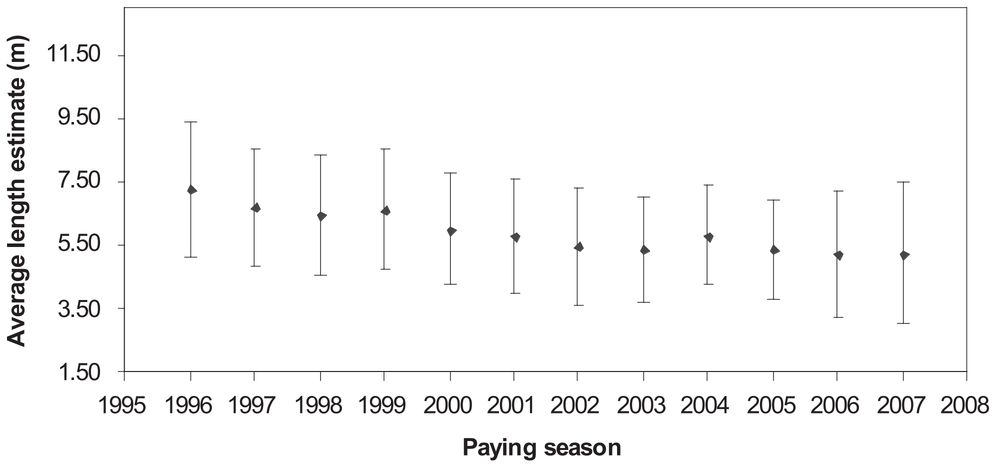

Table 1.

Size range of whale sharks interacted with between 1996 - 2007

Size range of whale sharks interacted with between 1996 - 2007

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Smallest	3	3	3.5	3	3	2.5	2.5	2	2.5	1.5	2	1.5
Largest	13	11	15	11	12	8.5	10	10	11	10	11	12

2002 to 2007. It must be noted that logbook length data estimates have not been assessed for accuracy, especially relevant as the estimates are made by industry staff with variable backgrounds, experience and generally no formal training in size estimation. It is therefore necessary that a study be conducted to determine the reliability of the length estimates.

Using extensive photo-identification records from Ningaloo from 1995 to 2006, Holmberg et.al., 2008 developed a population model that suggested a greater number of smaller individuals were present at Ningaloo in recent years. Size range records (see Table 1) support this hypothesis. This project will analyse length data to 2008 through size frequency distribution analysis to test this hypothesis against the industry logbook data.

Knowledge transfer

The data is partially analyzed annually and a report is prepared. These progress reports are provided to relevant government agencies, marine resource managers, whale shark industry members and the scientific community annually.

Earlier data (pre-2000) was used by Wilson et. al. (2001) to establish a relationship with ENSO events and whale shark abundance at Ningaloo reef.

Logbook data from 1996-2004 was presented by the Principal Investigator at the Inaugural Whale Shark Conference in Perth in 2005 and a paper was published in the Conference Proceedings prepared by the CSIRO (Irvine & Keesing, 2007, eds).

The data set from 1995 to 2004 was made available to AIMS researcher Dr Mark Meekan and it has been used in a recent publication relating to climatic variances on whale shark abundance (Sleeman et al., in press) and one publication on reduced length and abundance of whale sharks at Ningaloo (Bradshaw et. al., 2008).

Some data has been provided to social researchers. The Principal Investigator used some of the data in preparing a presentation for the 2nd National Wildlife Tourism Conference in 2005 and a paper has been accepted for publication in the Journal for Ecotourism.

A Landscope article has been written and will be published later in 2008 or early 2009.

A manuscript for scientific publication will be prepared to present the findings of the project to the broader scientific community. It is anticipated that a paper will be presented at the 3rd International Whale Shark Conference in the Philippines in 2010.

Next stage

The whale shark industry logbook data will give an indication of when the carrying capacity of the industry has been reached and what, if any, impacts this will have on whale shark interactions (requiring a separate study on behavioural response to interaction). Estimated whale shark size and gender data has been collected in vessel logbooks and some uncertainty in regards to error sources requires further analysis and research for accurate interpretation of this dataset.

Further analysis of the spotter pilot data is planned to provide better search effort data that can be correlated with other factors that may have an influence on inter-seasonal variability of relative whale shark abundance. This information will be used to assist in research efforts to determine factors effecting relative abundance trends at Ningaloo Marine Park.

Further training to improve size and sex data collection is recommended to improve data quality. Analysis on size estimation by industry staff, experienced recorders and accurate measurements is currently being undertaken through the not-for-profit group, Ecocean. More detailed size data analysis and accurate length measurements of whale sharks in the future will assist with management actions to address the indicative trend of reduced average size.

Acknowledgements

This information would not be available without the effort and participation of the Ningaloo Whale Shark Tourism Industry, Norwest AirWorks and the many Department of Environment and Conservation staff involved in the management of the industry. Many thanks to Kelly Waples and Alan Kendrick from the DEC Marine Science Program for reviewing this abstract.

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An analysis of sex ratio of Western Australian Humpback Whales migrating past North West Cape, Western Australia – implications for population size estimates

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Abstract

The current recovery rate estimates of the population of humpback whales that migrate along the Western Australian coast every year is approximately 10% yr-1. While past population size estimates are on the order of 8,000-14,000 (1999), the current size could be anywhere from 15,000 to 25,000 whales (50-100% of the estimated pre-whaling numbers). These values could represent underestimates, however, if in fact all whales do not make the annual migration. A sample of 258 biopsies were collected for sex determination during 2002 and 2003 off North West Cape Western Australia, which resulted in male skewed sex ratios in both seasons. During preliminary analyses, no sampling biases (towards sampling more males than females) could be detected that could be explained by differences in cue type, month, year, pod size, migration speed, sea state, swell, and direction of migration. Given that measurements of sex ratio in the Antarctic have shown evidence of fairly equal sex ratios, this preliminary study so far supports the suggestion that a portion of the females may not migrate north to the breeding grounds each season. Further investigation is planned and is required to tease out any further biases not considered here, and to confirm the corrected sex ratio.

Project description

Models of humpback whale population growth rates calculated on breeding grounds have assumed that all individuals migrate north from polar feeding areas each year (Paterson and Paterson, 1989, Byden et al. 1990, Bannister et. al., 1991, Bannister and Hedley, 2001). A sample of 2063 fetuses from the population now known as Breeding Stock D was shown to be almost a 1:1 ratio of males to females (Chittleborogh, 1965). It has therefore been generally assumed that equal numbers of males and females migrate to the breeding grounds each season and therefore the population models calculated are representative of the entire population. Brown et.al. (1995) attempted to change this perception of the sex composition of the migratory body with their discussion of why their biopsy samples of 180 Stock E (eastern Australia) whales were highly biased towards males. They pointed out that commercial whaling catches on the breeding grounds also appeared to be biased towards males (Chittleborough, 1965), despite the suggestion by Chittleborough that males were deliberately targeted to protect cow/calf pods. Brown et.al. (1995) concluded that the sex bias could be explained if not all females migrated north from polar feeding grounds each season. Other researchers have also recorded a male bias when analysing biopsy samples (Palsboll et al. 1992, Baker et al. 1998, Olavaria et al., 2006) but have yet to provide evidence that their sampling techniques or selection criteria have not been biased in some manner. In this paper we discuss a 2 year (2002-2003) sampling program to determine sex ratio of stock D humpback whales which was designed to specifically assess possible biases in biopsying whales from the population.

Current findings and their implications for management

Migratory Patterns West of North West Cape (from Jenner et al. 2008 – in review)

Humpback whale migratory behaviour west of NWC was described during a systematic study in 2003 (Jenner et al. 2008). Overall the order of southerly migrating whales consisted of mixed females (including those in early pregnancy) and immature whales first, followed by mature males and females in early lactation. During the northern migration west of NWC, almost all pods were adult-only pods travelling relatively quickly. During the southern migration swim speed decreased, which coincided with relatively long dive times, shorter surface intervals, and fewer blows upon surfacing (for adult-only pods). The majority of migrating pods west of NWC were single animals, and this in general did not appear to change significantly over the migration cycle (to breeding grounds, and back to feeding grounds). However, the region where most boat survey effort was concentrated (depths > 100 m), could represent the main migratory corridor for single pods, since a large number of pods with calves are known to enter Exmouth Gulf or to travel mainly in shallow waters < 100 m deep. Whether there is a consistent pattern in zonation (with distance from the coast), which is dependent upon sex, reproductive status and social organization, irrespective of pod density, remains unclear. However, given that sex has a large influence on behaviour, it seems convincing that sampling whales could be biases towards the sex that is more “visible”, hence more often targeted.

Sex bias – this study

A total of 72 males and 29 females were sampled in 2002 (Figure 1) resulting in a ratio of 2.5:1. During 2003 122 males and 35 females were sampled resulting in a ratio of 3.5:1. A General Stepwise Multiple Regression (using Statistica 5.5) was used to identify whether there were any relationships between the independent variables measured (month; year; cue type – breach, blow, etc.; direction of migration – south, north, milling; pod size; travel speed; sea state; and swell) and the dependent variable, which was the proportion of biopsied whales that were male. The analysis allowed for the detection of possible interactions among variables as well. If for example, males tended to breach more often or occurred more often in pods that were larger, then a greater detection of these pods would result in male biased sampling. The results showed that there were no significant relationships between independent variables and the proportion of males during the 2 biopsy seasons (multiple regression = $p > 0.05$).

Given that measurements of sex ratio in the Antarctic have shown evidence of fairly equal sex ratios, this preliminary study, as designed so far supports the suggestion that a portion of the females may not migrate north to the breeding grounds each season. Further investigation is planned and is required to tease out any further biases not considered here.

Knowledge transfer

This information is relevant to a large number of organisations, including government agencies, politicians, marine resource managers, and the scientific community. After further analysis the information will be most useful in the form of media, presentations, state and federal government access for relevant planning/policy processes, and reporting directly to the International Whaling Commission.

Next stage

The only possible remaining bias that could be influencing results is unequal biopsy sampling effort across bathymetric depths. The tracks were designed to maximize biopsy effort by targeting the main migratory body which could have resulted in weighted sampling in certain areas. Further analyses of the data we propose will correct for spatial effort prior to running a GSR.

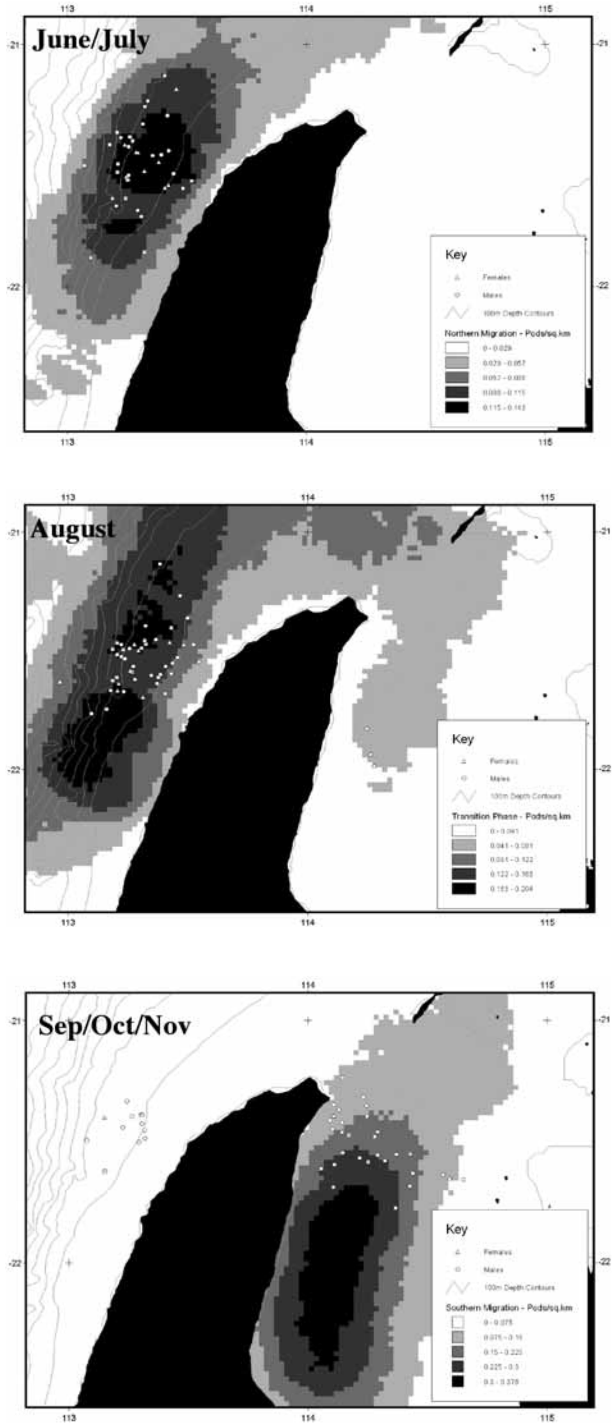

Figure 1.

The NWC study area showing the positions of biopsy sampled males and females during the northern, transition and southern periods of the migratory cycle in 2002/2003, overlaid on the preferred migratory path during the same period.

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The trophic ecology of the grazing sea urchin *Echinometra mathaei* within Ningaloo Marine Park, Western Australia: comparing the effects of different closure regimes on urchin distribution, recruitment and settlement

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Project contributions and collaborations

Research undertaken for this PhD project will be in part funded by the Ningaloo Collaboration Cluster (NCC), Component 1: Habitat Mapping and Biodiversity at Ningaloo Marine Park Western Australia, a CSIRO "Wealth from Oceans" initiative. This project will contribute to Component 1 of the NCC (Habitat Mapping and Biodiversity) which will provide a broad-scale, high resolution understanding of coastal habitats, biodiversity and land-use and how they affect the choice of human activities in the area and conversely, identify areas of high biodiversity that might be vulnerable to increased human use. Outcomes from this PhD project will also contribute to current marine science research initiatives conducted by the WA Department of Environment and Conservation (DEC) Ningaloo Research Program (NRP) and the W.A. Marine Science Institution (WAMSI Node 3). Data on bathymetry and the digital elevation model developed in Component 1 by Curtin University will also be made available for this project as well as be provided to the DEC NRP (WAMSI Node 3). Close links are also being established with the biodiversity component of the NRP to develop shared methods and joint research plans with Component 1 of the NCC.

Project description

Sea urchins can have a significant influence upon the ecological structure of coral reefs through bioerosion of substrata and also by affecting competition for space between corals and algae (Bak 1990, McClanahan 1998, Mapstone et al. 2007). However, the relative importance of the role of sea urchins in influencing the composition and structure of coral reef habitats has rarely been explored (Mapstone et al. 2007).

Urchins may be herbivores, omnivores, scavengers or deposit feeders depending on their habitat (Emlet 2002). They are mostly non-selective, opportunistic feeders that will browse on whatever plant or animal material is available (Baker 1982). Tropical species tend to have a prolonged to continuous spawning season, while temperate species reproduce annually with distinct spawning seasons (Emlet 2002). Non- brooding females are capable of producing thousands to millions of eggs, depending on their size and species. Some species with lecithotrophic (egg yolk feeding) larva take only a matter of days to develop and settle (Williams 1975, Scott et al. 1990, Emlet 2002). Unusually large urchin settlement events or population increases (e.g. caused by trophic cascades) can consequently result in overgrazing in a variety of benthic marine communities such as tropical coral reefs (McClanahan et al. 1996).

Ningaloo Marine Park provides an opportunity to study a near-pristine tropical coral reef environment that has not been affected by the over- exploitation of natural resources that has occurred in most other tropical reef systems of the World. Furthermore, this allows for comparisons in reef community structure between Ningaloo and other degraded systems.

The overall objective of this research project is to add to the general understanding of coral reef ecology and more specifically, advance the existing knowledge of the role of sea urchins in coral reef ecology at Ningaloo Marine Park. This study will examine marine grazers (particularly sea urchins), investigating their habitats, home range, reproduction, distribution, larval recruitment and settlement, and trophic relationships at Ningaloo Marine Park. The indirect effects of different closure regimes (e.g. Marine Protected Areas (MPA's) such as sanctuary zones) on urchin ecology within Ningaloo Marine Park will be examined at length, both temporally and spatially over the next two to three years and will provide important new information which will aid in the formulation of future management strategies for the conservation and stewardship of Ningaloo Marine Park.

The proposed aims of the project will be achieved by:

1. Field validation and refinement of an original Hyper-spectral data library from which new, state of the art, custom-made benthic habitat maps of the Ningaloo Marine Park will be created for use in this and other related projects.

2. Identifying various coral reef habitats, macro-algae assemblages and macro-invertebrate populations in selected areas within Ningaloo Marine Park (back reef, lagoon and near-shore areas), with a view to targeting urchin habitats both in and out of MPA's.
3. Identifying typical urchin habitats and comparing variability of urchin habitat community structure between MPA's and non-protected areas.
4. Investigating any differences in trophic relationships of urchins in MPA's and non-protected areas to determine trophic structure variability between similar habitats.
5. Determining the possible impacts of current and future closure regimes on lagoonal trophic structure within Ningaloo Marine Park.

Field of research

The field of research contributed to by this project can broadly be described as coral reef ecology; more specifically it will contribute to the fields of coral reef lagoonal trophodynamics and marine macro-invertebrate ecology, particularly in relation to sea urchin predation, distribution, reproduction, larval recruitment and settlement. The hyper-spectral habitat mapping component of the study will also contribute to the field of coastal geography and geomorphology.

Proposed outcomes

Each component of the study should provide data for at least one manuscript to be submitted to a high impact international refereed journal. An overview will be presented at the 12th International Coral Reef Symposium in 2011. Presentations will be made to the annual Ningaloo Symposium in 2009, 2010 and 2011. This will ensure the results are communicated to a wide range of marine scientists internationally and within Australia.

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Foraminifera from Ningaloo Reef, Western Australia: systematics and taxonomy

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Abstract

Over 400 species of foraminifera from the back-reef lagoon of Ningaloo Reef were identified and described in detail. About a quarter of these are believed to be new and ten new species names have been applied. The species descriptions are supplemented by over 4000 SEM and light microscope images of whole and dissected specimens, as well as replicas. The wall microstructure of over 130 species of miliolid foraminifera is illustrated and described, and new insights into the taxonomic implications of miliolid wall structure are proposed.

The foraminiferal fauna is a shallow water sub-tropical assemblage with close affinities to faunas described from inner-neritic environments of the Indo-Pacific and Western Pacific regions. Many tropical species common to coral reefs of the Indo-Pacific region are absent or rare. Some species common in the cooler waters in southern parts of Australia are present or common in the samples.

Project description

The objective of the project was to document the taxonomy of common species of foraminifera from Ningaloo Reef. It was undertaken to fill the gap in knowledge of foraminifera from inner-neritic environments of Western Australia. A secondary objective was to systematically analyze the wall microstructure of porcelanous (miliolid) foraminifera to investigate trends in the microstructure that may be related taxonomically.

About 400 sediment samples from the Ningaloo Reef back-reef lagoon were analysed for their foraminiferal content. Thirty of these samples with a high diversity of species were intensively picked and common species identified. Each species identified was illustrated by SEM and light micrograph and then compared to type description and illustrations and in some cases to the type specimens themselves or to specimens from the type locality. Unidentified species were compared to descriptions and illustrations of foraminiferal taxa globally for stability of species concepts. Miliolid taxa were also examined using high resolution SEM to resolve details of the wall microstructure.

The number of undescribed species encountered in the Ningaloo Reef samples is partly a result of the uniqueness of the environment at Ningaloo and also to the lack of research and understanding of the area. The taxonomic foundation laid by this research will allow for more applied research on foraminifera as proxies to environment and as monitoring tools.

Current findings and their implications for management

Foraminifera were found to be uncommon in most of the Ningaloo Reef back-reef lagoon sediments, typically constituting less than 1% of the lagoonal sediment. In channel muds and deeper water (20-30m) parts of the lagoon with a fine sandy substrate the foraminiferal diversity and abundance are highest. Immediate back-reef areas have a higher than average foraminiferal content but the diversity is low.

Over 400 species of common modern benthic foraminifera, representing 156 foraminiferal genera, were described and illustrated; including the application of ten new species names and the description of 115 species that are probably new. Many more species were found in the samples, but these are extremely rare with typically only a few representatives found. The rare species were omitted from this study.

The species described from Ningaloo Reef have the strongest affinity to Indo-Pacific faunas described in the literature and over half of the species appear to have restricted geographic ranges. The restricted ranges identified include species that have only been described from the northern Australian-Indonesian region (central Indo-Pacific region: 71 species), species that have only been described from the Indian Ocean, Red Sea and the western Indo-Pacific region (28 species) and species that have only been recorded in the central Indo-Pacific region and the tropical Pacific Ocean (including the eastern Pacific region: 119 species). Forty four species have, as yet, only been described from Ningaloo Reef and 18 species from Western Australian waters. The remaining 124 of the species found have a cosmopolitan distribution.

Distinctly estuarine foraminiferal assemblages were found in the swamp at Mangrove Bay and in the stream at Yardie Creek. Foraminiferal species restricted to these areas include *Ammonia tepida*, *Elphidium* cf. *E. williamsoni*, *Monspeliensina vulpesi*, *Trochammina inflata*, and *Paratrochammina simplissima*. Additional species associated with these assemblages include *Quinqueloculina seminula*, *Quinqueloculina* sp. 1, *Q. neostriatula*, and *Miliolinella chiastocytis*. These species are also found in samples from the open lagoon. Rare specimens of *Neorotalia calcar*, *Heterostegina depressa* and other typical lagoon species found in these restricted assemblages are common in the open lagoon and are probably transported.

Baculogypsina, *Baculogypsinoides*, *Calcarina*, and *Schlumbergerella* species that are very common in coral reef sediments of the present day Indo-Pacific and Western Pacific (Lobegeier 2002, Renema 2003) are completely absent from Ningaloo Reef and coral reefs to the south. Loeblich and Tappan (1994) recorded species of *Baculogypsinoides* and *Calcarina* from the Timor Sea region, and the author has observed common *Calcarina* and *Schlumbergerella* in samples from Ashmore Reef and Timor Leste. Currently the presence of these “coral reef” genera between Ningaloo Reef and Ashmore Reef is not known. An examination of the few samples from the Western Australia coastline north of Ningaloo Reef at the author’s disposal, suggests that the genera are not present in coastal waters with known coral growth, although these are not significant reefal communities. Examination of the offshore reefs at Scott Reef and the Rowley Shoals is needed to determine the southern extent of these genera and possible environmental restrictions on their distribution.

Larger foraminifera with a strong tropical affinity that are abundant in the Ningaloo Reef samples include *Amphistegina lessoni*, *A. lobifera*, *Homotrema rubra*, and *Alveolinella quoyi*. Some taxa including *Lamellodiscorbis dimidiatus* and *Annulopatinella annularis*, which inhabit seagrass meadows, are much more common further south along the Western Australia coastline than in the Ningaloo Reef samples.

The microstructure of the outer-wall layer was examined for over 130 species of miliolid foraminifera. Examination of outer-wall microstructure shows that seven distinct construction types are present. The construction types are consistent within a species, and appear to be largely consistent within a genus. A skeletal structure of aligned calcite rod-shaped crystals is shown to be present in the Larger miliolid foraminiferal genera *Alveolinella*, *Amphisorus*, *Borelis*, *Monalysidium*, *Peneroplis*, and *Sorites*. A similar structure was not observed in any of the “smaller” miliolid species examined.

Knowledge transfer

The research is structured as a taxonomic guide to the foraminifera from Ningaloo Reef, with comments about characteristics useful for the correct identification of species and correct generic assignments. Comparisons with type specimens and similar species are made to further assist species identification. This information mostly benefits the scientific community in particular researchers working on foraminifera, or those intending to work with this taxonomic group.

The correct identification of foraminifera in future studies will facilitate the use of foraminifera-based environmental models in interpreting and understanding the inner-neritic environments of Ningaloo Reef and Western Australia. This includes models developed elsewhere in Australia and globally. It will also allow the application of models developed for Ningaloo Reef to be applied to reefal communities elsewhere, particularly those in transitional tropical to sub-tropical environments and the broader Indo-Pacific region.

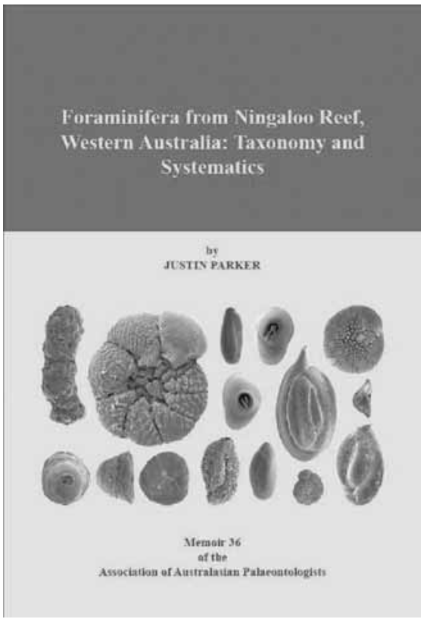

Figure 1.

Cover of the Association of Australasian Palaeontologists Memoir 36.

The research will be published as Australasian Association of Palaeontologists Memoir 36 later this year (Figure 1).

Next stage

During the study, a systematic count of foraminiferal species abundances was conducted. This will be combined with grain-size data and data collected about the habitats from where the samples were collected, to form predicative models for the use of foraminifera as proxies to habitat.

This data will be incorporated into a dataset of Holocene foraminifera from the western coastline of Western Australia, compiled by David Haig of the University of Western Australia. This data set will allow distribution patterns of inner-neritic species to be analyzed and latitudinal extents of species determined.

Acknowledgements

Many people have provided assistance with this project over the years, but in particular the greatest debt of gratitude is owed to David Haig, who provided the inspiration and encouragement, without which this project would not be possible.

The Association of Australasian Palaeontologists Chris Simpson of the Department of Environment and Conservation, Government of Western Australia, and are thanked for their support for the publication of the monograph.

Physical environment

Mapping habitats and biodiversity of Ningaloo Reef lagoon using hyperspectral remote sensing data

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This project is part of the CSIRO Flagship Wealth from Oceans, Ningaloo Cluster: "Reef use, biodiversity and socio economics for integrated management strategy evaluation of Ningaloo". This project is run from Murdoch University in collaboration with Curtin and Queensland Universities. Airborne hyperspectral data have been acquired by HyVista through the efforts of AIMS and sponsored by BHP Billiton.

The project is focusing on the mapping of habitats and biodiversity of the Ningaloo Marine Park. This is being achieved through a combination of state-of-the-art hyperspectral remote sensing techniques, coupled with biodiversity field surveys of the area.

Specific aims are to:

1. Use the hyperspectral data to create a bathymetry data set and broad-scale classification of the lagoon habitats over the extent of the Marine Park (Curtin University).
2. Develop a radiation transfer model and optimisation code that can be used by researchers on a number of different systems to reprocess atmospherically corrected reflectance data (Curtin University).
3. Develop a high-resolution characterisation of the reef and shallow water habitats of the Ningaloo Marine Park that will provide the basis for future multiple use management and planning of the area.
4. Develop a high resolution characterisation of terrestrial land use and distribution in relationship to marine habitats.
5. Qualitatively and quantitatively describe the biodiversity values of selected areas of the reef in relationship to the bio-physical environment, patterns of reef use and access from land, linking these with physical and/or biological surrogates to enable specific biodiversity values to be applied across the entire Ningaloo Marine Park.
6. Identify biodiversity hotspots and develop an understanding of the environmental and habitat factors that explain the distribution of these hotspots.

Airborne hyperspectral data were collected by HyVista in April 2006 over 3500 km2 covering the whole Ningaloo Marine Park. This is the largest hyperspectral coral reef survey to date in the world and provides images at 3.5m spatial resolution for a 1km wide terrestrial coastal strip and out to 20m depth over lagoon areas. Hyperspectral remote sensing data are corrected for atmospheric, air water interface and water column effects. This, physics-based approach, promotes automatisation and the removal of subjectivity from the classification process, allowing improved transferability to additional sampling locations and extension of the monitoring to other seasons.

Optical remote sensing techniques, especially hyperspectral sensors can provide an efficient and cost-effective approach to mapping and monitoring the condition of reefs over large areas because of their capability to identify individual reef components on the basis of their detailed spectral response. The aim of this study is to develop a reliable and repeatable procedure for mapping submerged coral reefs using airborne hyperspectral data.

Spectral data collection

Spectral reflectance of corals, macroalgae and sediment from several habitats at different locations were measured underwater in the field with an OceanOptics2000 hyperspectral spectroradiometer. Field samples were collected during airborne remote sensing data acquisition in April 2006 (2 weeks), April 2007 (2 weeks), September/October 2007 (1 week) and December 2007 (2 weeks).

Spectral reflectance from different substrate types including sand, coral and brown algae were collected in situ to assess the range of spectral variability that may be found in each cover type. Benthic group code for survey of sessile benthic communities were adopted from AIMS (Page et al., 2001). A sampling strategy was used to measure the spectral reflectance of as many homogenous substrates as possible to characterise the spectral signatures of each species. Data collection was performed following the methods described in Hochberg and Atkinson (2000,2003).

These underwater spectra were used for development of algorithms for automated applications to image classification. A genetic algorithm technique was used to determine optimal waveband combinations ideal for identification of substrate types by remote sensing.

Initial results show that in situ reflectance spectra of coral reef substrates were significantly different for various spectral wavelengths. Based on a linear discriminant analysis, the in situ spectra of six benthic groups (branching Acropora, digitate Acropora, tabulate Acropora, massive corals (e.g.

Porites), submassive corals (e.g. Pocillopora) and macroalgae) could be classified to 90 % accuracy using as few as six optimally-positioned bands in the visible wavelengths. Statistical tests such as unsupervised classification (Principal Component Analysis) and a distance measure index (Jeffries-Matusita) were used to confirm species separation and indicated that hyperspectral remote sensing techniques offer great potential in mapping coral reef habitats. A preliminary classification of major habitat groups was applied to airborne hyperspectral remote sensing data from HyMap acquired in November 2005 and April 2006 over the Yardie Creek area and Coral Bay. The images were corrected for atmospheric, air-water interface, and water column effects using the physics-based Modular Inversion & Processing System. This has the advantage of removing subjectivity from the classification process, approaching an automated classification which allows improved transferability to other sampling locations and monitoring applications. The retrieved bottom albedo image was then used to classify the benthos, generating a detailed map of benthic habitats, followed by accuracy assessment.

The outputs of multitemporal image analysis allowed us to create quantitative maps of selected substrate cover types. These have now been partly validated using our own data and data from 17 sites monitored by DEC (Dr Suzanne Long) over the past 10 years.

Comparison of the preliminary marine habitat maps with the field results of description and cover is very encouraging. The results indicate that the spectral response of corals can be determined up to a depth of 10 m and show that hyperspectral remote sensing techniques provide an opportunity for developing baseline mapping and monitoring programs for coastal and coral reef ecosystem health indicators.

Terrestrial data processing is focusing on mapping tracks, invasive grass species (buffel grass) and mapping broad coastal vegetation communities.

The following landforms components have been identified for mapping:

- foredunes, relic foredunes, relic foredunes plain, parabolic dunes, active parabolic dunes,
- coastal storm surge flats, inlet splits (relic), interdune depression/flat, aeolian flat/ridge,
- deflation basin, saline flat/salt pan, hypersaline pools, calcarenite rocks and sand plains.

Vegetation components are assessed through vegetation indices as well and spectral mixture mapping techniques. The following vegetation components have been identified as “mappable” using hyperspectral data: trees (Eucalyptus, acacias, Casuarina, Tamarisk (non native), palms); shrubs (ficus, halophytes, coastal shrubs, mangroves; grasses (buffel (non native), green grass in settlements) and coastal/dune complex plants (spinifex, saltbush, acacia).

Data layers generated from marine and terrestrial data processing will comprise thematic maps of cover type showing habitat distribution as well as probability maps for each of the habitat components. These data will assist in current and future management of activities in the park as well as future planing and monitoring programs.

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Growth history, geomorphology, surficial sediments and habitats of the Ningaloo Reef

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Abstract

This research aims to identify evolutionary characteristics relevant to the maintenance of marine biodiversity of the reef and continental shelf at Ningaloo. Coring and outcrop interpretation, U-series dating and shallow seismic lines provide the data on Quaternary growth history and evolution. GIS mapping using aerial and acoustic remote sensing, alongside video transects, sediment grabs and benthic sled sampling, have been used to characterise contemporary geomorphic zonation and structure, carbonate sedimentary environments, benthic habitats and coral community assemblages.

Pleistocene foundations and ancestral topography played a major role in the establishment of Holocene reef development and are the primary physical controls on contemporary geomorphology and habitats. Encrusting coralline algae, coral, macroalgae, turf algae and seagrass habitats thrive across geomorphic zones of the back-reef. Preliminary analysis of coral community structure has defined distinct assemblages within reef flat, lagoonal and reef pass habitats. On the shallow fore-reef slope there is a veneer of coralgal growth on multiple backstepping spur and groove systems. Hard corals are rapidly replaced by rhodolith beds at the transition from lower slope-inner shelf platform, providing the hard substrate for sessile filter-feeding communities. Submarine fans adjacent to reef passes complicate this pattern locally. On the open mid-outer shelf, sediment veneers over limestone pavements and 'large to very large' dunes are interrupted by extensive ridge and pinnacle systems. Exposed surfaces are colonised by prolific sponge, gorgonian and bryozoan "gardens". These are prevalent near continental slope canyons, which are sites of cold water, nutrient-rich upwelling; ideal conditions for cooler-water carbonate production. There is a strong transition from photozoan-reef (warm water/low nutrient) to heterozoan-carbonate ramp (cold water/high nutrient) producers across the shelf Sediments are almost wholly biogenic in origin consisting of older relict and reworked grains mixed with modern skeletal fragments. The sediments have assumed the character of the benthos and are a proxy for the habitats that produced them. Depth consistent sediment facies can be recognised across the shelf and latitudinally, based on component composition and grain size characteristics.

An understanding of reef evolution and the strong spatial relationships between ancestral foundations, geomorphology and contemporary ecology is essential for the ongoing conservation and management of the Ningaloo Marine Park.

Project description

Geophysical factors can be significant in describing the distribution of habitat types and benthic biota over broad geographic regions. The classification of benthic habitats and communities based on these factors is central to the ongoing conservation, monitoring and management of biodiversity at the Ningaloo Marine Park (NMP). This study aims to improve understanding of the underlying geology, geomorphology and surficial deposits of the reef system and continental shelf and identify their controls on benthic habitat and community distribution.

Coring and outcrop interpretation, U-series dating and shallow seismic lines provide the data on Quaternary growth history and evolution of the reef. A detailed record of sea-level and paleo-environmental conditions will be established. The relationship between reef growth and sea-level fluctuations during the Holocene (last 10,000 years) will provide a basis for assessment of the future impact of climate and sea-level change on reef and coastal ecosystems.

The contemporary geomorphology, carbonate sedimentology and habitat distribution of the reef and shelf will be characterised through the use of GIS and seabed mapping techniques, using remote sensing imagery and acoustics, bottom sampling techniques and benthic video. For the inshore component (<20m) the project will focus on mapping the reef system using visual interpretation of aerial photography and hyperspectral imagery, and collecting ground-truthing data including: diver operated benthic video transects, photographic quadrats, sediment grabs and rock samples. A hierarchical classification scheme has been created to define and delineate shallow-water coral reef habitats based on geomorphic zonation, geomorphic structures/features and the associated benthic cover. GIS maps for surficial sediment facies are being generated using grain-size analysis, quantitative component counts and carbonate mineralogy using X-ray Diffraction (XRD). These maps are at a sufficient scale and resolution needed for ongoing research and monitoring to support management needs. Finescale habitat and coral community assessments, have been undertaken in specific back-reef (reef flat, lagoonal and reef pass) habitats at five sites in the northern Ningaloo Reef.

The offshore component of the project (~20-110m) is being undertaken in collaboration with WAMSI Project 3.1.1 to characterise the offshore biodiversity and develop broadscale habitat maps of the Marine Park. Single beam and multibeam acoustic surveys, sediment grabs and dredged rock samples have been used to characterise and map geomorphic and sedimentary environments. A towed-video system and benthic sled were used to sample habitat structure and the diversity and abundance of invertebrate communities (sessile and mobile). Additional analysis using multivariate statistics will examine the geophysical variables that are predictors for the distribution of these assemblages. The relationships determined will inform our understanding of benthic habitat variability and aid in the production of broadscale habitat maps of the NMP.

Current findings and their implications for management

Initial stratigraphic observations of reef cores from the Exmouth Gulf marina have identified ~5 m of Holocene reef growth as compared to a maximum Holocene cored thickness of ~7 m seaward of the reef crest at Tantabiddi. The Holocene section at Exmouth consists of coral framestone dominated by massive and branching corals and bioclastic skeletal grainstone to rudstone. A number of geological units underlie the Holocene reef: the Last Interglacial (LI) reef coral framestone to rudstone, and coralline algal bindstone; a marine bioclastic unit; and an alluvial fan facies containing Tertiary pebbles and gravel from the Cape Range. These foundations have been central to the establishment of Holocene reef development, contemporary geomorphology and initiating modern habitats and communities. Preliminary coring at Winderabandi (4.7 m of Holocene reef; outer reef flat) and south of Sandy Bay (10 m of Holocene reef; inner reef flat) has shown the modern reef is relatively thin and overlies the more extensive LI reef (125 U/Th ky) which developed during a period of stronger Leeuwin Current flow. The relationship between these two events of reef growth and the ancestral foundations of the modern reef will be further investigated. Additional field work and dating is underway to provide a full picture of reef growth, evolution and paleo-environmental conditions at Ningaloo.

Broadscale mapping of the reef has developed GIS layers for major reef geomorphic zones, detailed reef structure and major benthos for the entire Marine Park. Preliminary analysis of photo-quadrates for Osprey SZ has recorded a total of 25 coral genera, dominated by *Acropora*, *Montipora*, *Seriatopora* and *Porites*. The most speciose genus is *Acropora* restricted largely to reef flat habitats. On the inner reef flat, dominant *Acropora* sp. includes *corymbose A. valida*, *A. millepora*, *A. nasuta* and tabular *A. spicifera* and *A. hyacinthus*. In deep inter-reef gutters, branching *Seriatopora caliendrum*, massive *Porites* sp. and *Goniastrea* sp., and *caespitose Acropora* sp. are common as well as the soft coral *Sinularia* sp. Within the lagoon, limestone ridges provide sheltered habitats for communities dominated by branching *Seriatopora caliendrum*, submassive/encrusting/laminar *Montipora* sp. and massive *Porites* sp. Lagoon sand flats with scattered coral/algae have low cover and diversity and include mixed communities dominated by *Favia* sp. The reef pass coral/rubble habitat includes branching *Seriatopora caliendrum*, *corymbose Acropora valida* and *A. millepora*, submassive *Montipora* sp. and *Porites* sp., and submassive *Millepora* sp.. Inshore algal pavements have low cover and diversity, and are dominated by branching *Stylophora pistillata* and massive *Plesiastrea versipora*. Additional investigations will further quantify the finescale variability of habitats and coral community structure for all sites and determine geophysical controls on distribution patterns.

A number of large geomorphic features have been identified on the continental shelf that are important for habitat development. These include: the inner shelf relict reef platform; inner-mid shelf submarine fans; extensive mid-outer shelf dune fields; mid-outer shelf ridge and pinnacle systems and continental slope canyons. The shelf within the northern NMP is narrow and preliminary results show a clear zonation of geomorphology (Figure 1) and associated habitats across the shelf (Figure 2).

There is a strong association between geomorphology and benthic habitats with communities taking advantage of the availability of LI substrates. The hardbottom is mainly composed of a fossilised limestone surface, karstified due to glacial lowstand subaerial exposure. In the shallow fore-reef slope, there is a thin veneer of Holocene coralgal growth on multiple backstepping spur and groove systems. Between 30-40 m depth hard corals rapidly disappear and are replaced by a mixed, deeper-water, sessile filter-feeding community. This transition, between the base of the fore-reef slope and the inner shelf relict reef platform, is characterised by reef rubble and rhodoliths that supply the hard substrate for a diverse community dominated by crinoids, sponges, turf algae, Halimeda and soft corals (gorgonians, sea whips). On the inner-mid shelf submarine fans, formed from the offshore flushing of lagoon sediments through reef passes, complicate this pattern locally. Rippled sands, with no epibenthos, are commonly associated with these features. On the open mid-outer shelf, sediment veneers over limestone pavement and large dunes are interrupted by low-high relief ridge and pinnacle systems. Extensive linear ribbons, 'large-very large' asymmetrical and barchan type dunes indicate currents towards the NE and NNE. Communities of sponges, crinoids, bryozoans, soft corals, sea pens and hydroids are patchy in these regions with higher abundance associated to exposed substrates. In areas of lower energy, bioturbation is evident from echinoderm feeding traces, polychaetes and burrowing fish and a diverse infauna have reworked the sediments to

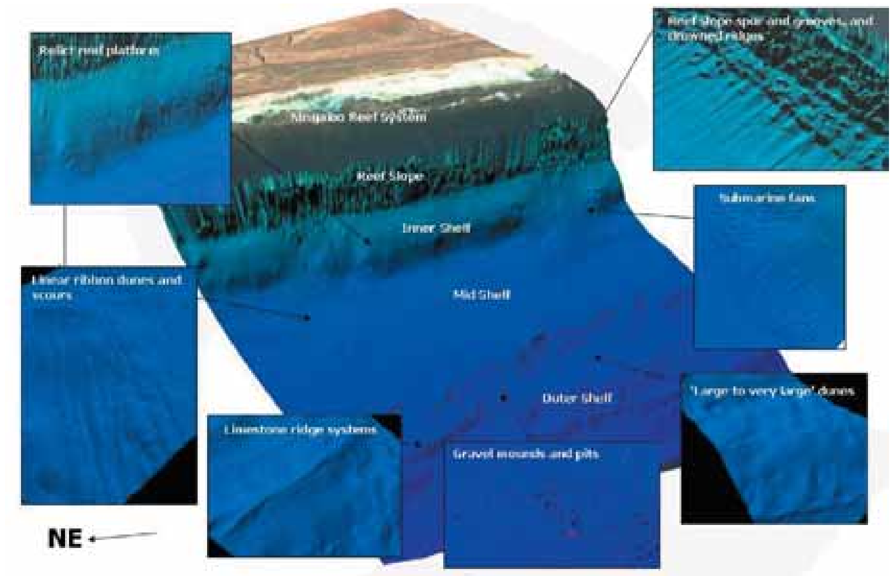

Figure 1.

Cross-shelf example of geomorphology and sedimentary environments in the Mandu region of the northern Ningaloo.

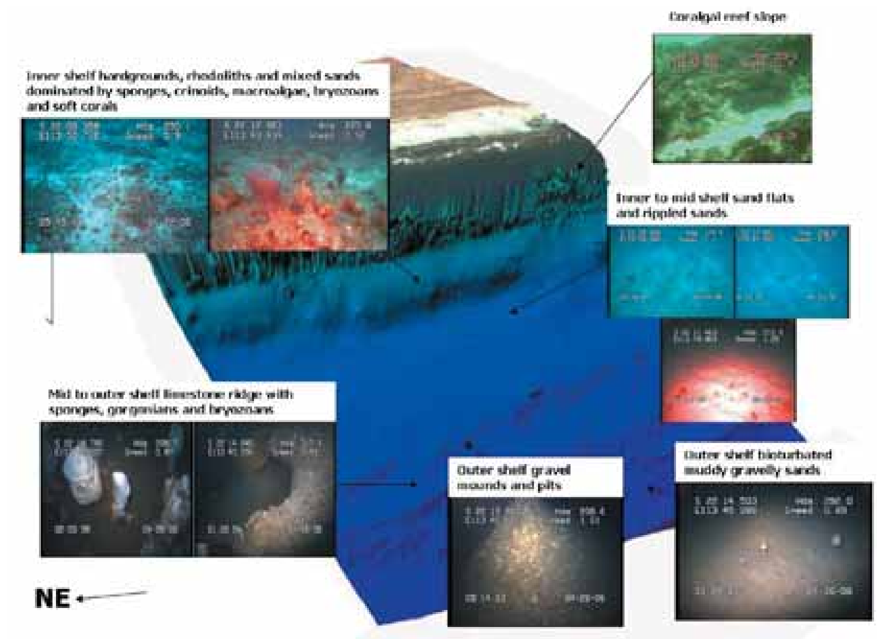

Figure 2.

Broadscale habitat zonation across the northern Ningaloo shelf at Mandu.

build mounds and burrows. Fields of large gravelly mounds occur in depths of ~95 m with basal diameters of up to 20 m. A number of ridges have been identified at various depths with prominent and extensive systems on the mid-outer shelf (~70-125 m). Their lengths range from hundreds of metres to tens of kms with widths up to tens of metres, creating an uneven bottom with up to several metres relief. These features may represent drowned back-stepping reefs and/or paleo-shorelines. The Last Glacial (~20 ky) shoreline has been identified at the 125 m depth contour. Ridges are colonised by high cover of exotic sponge, gorgonian and bryozoan "gardens", some of which are likely to be new species. Diversity is particularly high in areas adjacent to the continental slope canyons which bring nutrient rich, cold-water upwelling to the shelf edge; ideal conditions for cool-water carbonate production. A more complex history of constructional and pre-existing antecedent topography exists at Cloates SZ, where paleo-stillstand escarpments and shorelines, and very high-relief stepwise fossil reefs and pinnacles, support a diverse coralgal and sponge community. South of Point Cloates there is a marked transition in bathymetry with a gentler and wider shelf to the south. Rhodolith and sandy habitats are common in the southern part of the Marine Park. An offshore sinuous ridge system at Red Bluff again provides the hard substrate for a diverse sponge community.

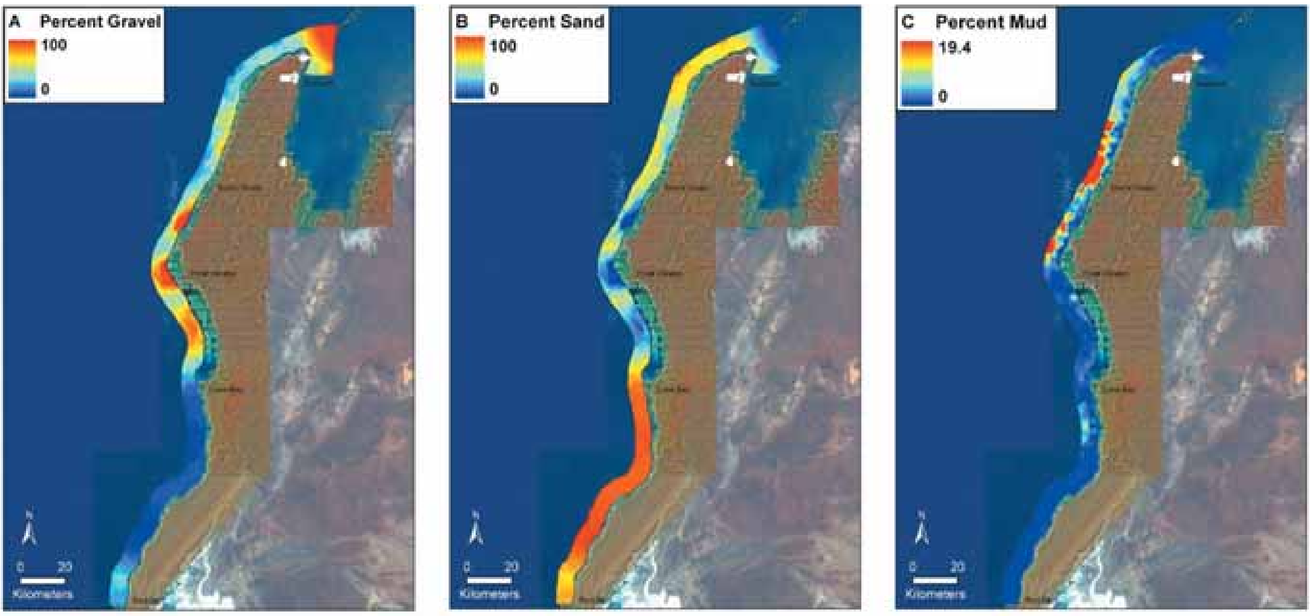

Figure 3.
Grain size distribution maps for the Ningaloo continental shelf.

There is a strong transition from photozoan-reef (warm water/low nutrient) to heterozoan-carbonate ramp (cold water/high nutrient) producers across the Ningaloo shelf. The importance of calcium carbonate secreting organisms to the surficial sediments is evident, with communities dominated by corals, red coralline algae, Halimeda, bryozoans, benthic forams, molluscs and planktic forams. Sediments are almost wholly biogenic in origin consisting of older relict and reworked grains mixed with modern skeletal fragments. The sediments have assumed the character of the benthos and are a proxy for the habitats that produced them. Depth consistent sediment facies can be recognised across the shelf and latitudinally, based on component composition and grain size characteristics (see grain size example Figure 3).

Knowledge transfer and next stage

This project will generate a number of outputs including GIS layers and maps for: bathymetry, seabed texture, geomorphology, sedimentary environments and habitats relevant for ongoing research and monitoring to support management needs at Ningaloo. Current project outputs include a number of management reports and presentations. There will be four pier-reviewed papers that will form the PhD thesis of Emily Twiggs due for completion early 2009 and a Masters thesis by Sira Tecchiato. Additional fieldwork is planned for the growth history component due for completion in 2009. There will be further ongoing collaborations with WAMSI Ningaloo Projects 3.1.1 and 3.2.2 culminating in additional journal papers, reports, GIS products and maps for Ningaloo. Terrestrial groundwater outflows into the reef lagoon will be investigated in a new project (WAMSI Ningaloo Project 3.10) to establish flow pathways and assess potential impacts on habitats and biodiversity.

Acknowledgements

This project is supported and funded by WAMSI and AIMS. It includes shared fieldwork and data with WAMSI Project 3.2.2, in particular Ben Fitzpatrick and Euan Harvey of UWA, and CSIRO Wealth from Oceans Project 1, including Halina Kobryn and Nicole Pinnel of Murdoch University. Collection of hyperspectral imagery was funded by BHP-Billiton through AIMS and collected and provided by HyVista Corp. Atmospherically corrected reflectance, bathymetry and benthic cover products were processed and provided by the Remote Sensing and Satellite Research Group at Curtin University, with particular thanks to Wojciech Klonowski. Thanks to DEC for the use of research facilities, to the crew of the RV Cape *Ferguson* and *Solander*, and ANU for assistance with coring equipment.

Hydrodynamics of fringing reef systems: Ningaloo Reef, Western Australia

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Abstract

The response of the circulation of Ningaloo Reef (the largest fringing coral reef in Australia) to wave, wind and tidal forcing was investigated using field data and preliminary output from a numerical model. A 6-week field experiment measuring waves, currents, and water levels was conducted during April-May 2006, which focused on the dynamics of flow within a representative reef - channel circulation cell (one of hundreds that comprise the overall system). Results from the study indicate that wave-forcing is the dominant mechanism driving the circulation of Ningaloo Reef, with lagoonal flushing times of 5-8 hours under typical offshore wave conditions. Cross-reef wave-driven currents, however, were significantly weaker (~0.1-0.2 m/s) than expected from the reef literature, likely due to the presence of considerable wave setup inside the shallow lagoon of this fringing reef. Preliminary results from a coupled wave-circulation numerical model, presently under development, are discussed.

Project description

The Ningaloo Reef tract extends approximately 260 km along the North-West Cape of Western Australia (Figure 1a). Unlike the Great Barrier Reef, which is separated from shore by an expansive coastal lagoon, Ningaloo Reef lies adjacent to shore. It is therefore classified as a fringing reef, making it the largest fringing reef system in Australia (Taylor and Pearce 1999). The reefs that comprise Ningaloo are located between a few hundred meters to a maximum of 7 km offshore, and are separated from shore by lagoons having mean depth of 2-3 m (Taylor and Pearce 1999). These reefs are broken every few kilometers by gaps, forming relatively deep channels through which a majority of the water exchanged between the lagoons and ocean is believed to occur.

Broadly speaking, the circulation of reefs can be driven by a number of forcing mechanisms including waves, tides, wind, and buoyancy effects (Monismith 2007). The relative importance of each mechanism varies among reefs and is a function of both a reef's geomorphology and the forcing conditions present at the site.

Relatively few studies have focused on the physical oceanography of Ningaloo Reef, but have suggested that breaking waves drive the dominant circulation patterns throughout much of this system (e.g. Hearn et al. 1986; Brinkman 1998). Conceptually, a wave breaking near the reef crest increases the mean sea level in the surf zone ("wave setup"), establishing a pressure gradient that drives a cross-shore flow across a shallow reef flat and into a deeper lagoon (Figure 1b). On fringing reefs bounded by a shoreline, water entering the lagoon must return to the ocean through narrow gaps (channels) in the reef. Therefore, considered as a whole, the circulation of Ningaloo Reef can be thought of as being comprised of up to a hundred of these individual reef-lagoon-channel circulation cells. Although a number of analytical models have been developed to predict wave-driven flows on reefs (e.g., Symonds et al. 1995; Hearn 1999; Gourlay and Colleter 2005), such models have been derived by solving simplified forms of the 1D cross-shore mass and momentum equations. While these 1D approaches may be suitable for reefs that are not bounded by a coastline (e.g., atolls and barrier reefs), it is unclear (largely due to a lack of field data) whether these existing reef models can be utilized on fringing reefs such as Ningaloo where the flows are inherently 2D.

The goal of the present study was to conduct a detailed field study into the dynamics governing the circulation of an ~5 km section of Ningaloo Reef centered at Sandy Bay (Figure 1b). This site was chosen because the reef appeared, from aerial photographs, to have morphological characteristics fairly representative of Ningaloo as a whole. In particular, the field data collected will serve as the foundation for the development and validation of a coupled wave-circulation numerical model, initially focused on this section of Ningaloo. Future work will concentrate on upscaling the model to simulate the circulation over much larger sections of Ningaloo [*O*(100 km)]; such a model will ultimately help to improve predictions of the transport of material (e.g. nutrients, contaminants, larvae, waterborne pests, etc.) within Ningaloo Marine Park, predictions upon which a variety of regulatory and management decisions can eventually be made.

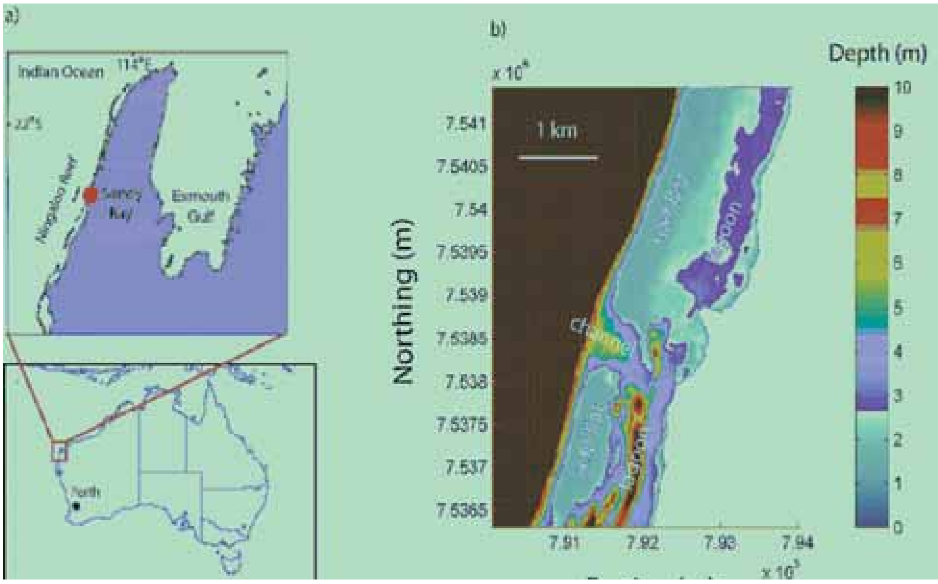

Figure 1.

Ningaloo Reef, Western Australia.
a) Field site (Sandy Bay) on the North West Cape.
b) Bathymetry derived from hyperspectral imagery, highlighting the dominant morphological features (note that depths >10 m are not shown).

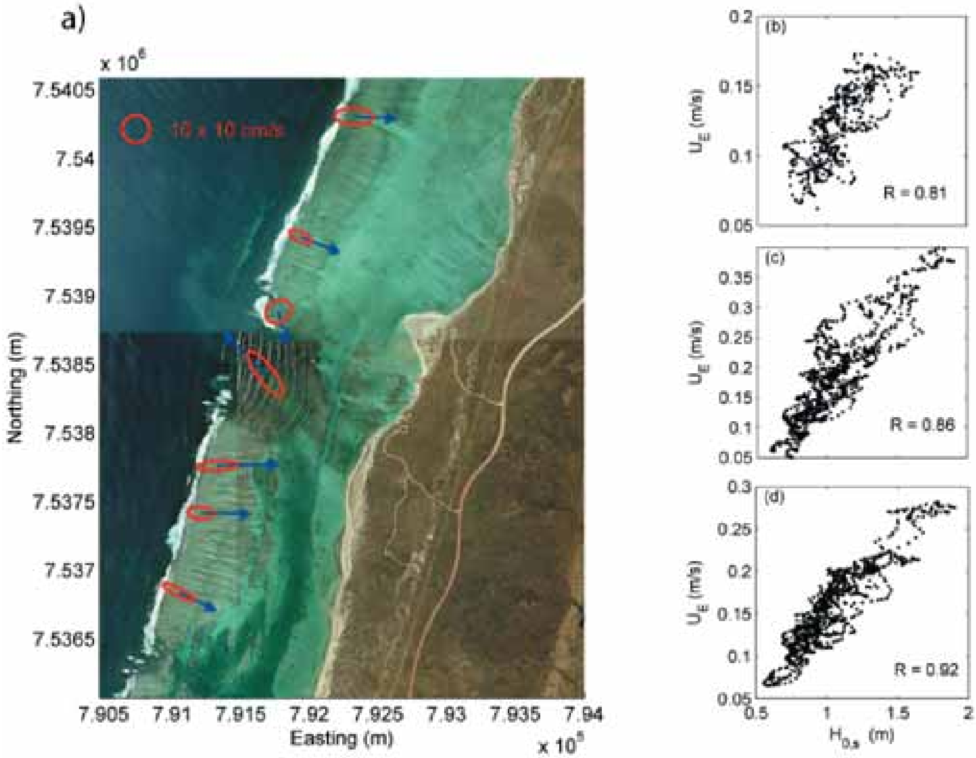

Figure 2.

a) Experiment-averaged current vectors (blue) and velocity variance ellipses (radii represent one standard deviation). Depth-averaged current speed as a function of offshore significant wave height, measured on the b) north reef flat, c) channel, d) south reef flat.

Field experiment and numerical model

An extensive field experiment was conducted at Sandy Bay from April 10 to May 30, 2006. A large array of instruments including 12 Acoustic Doppler Current Profilers (ADCPs), 9 single point current meters, and a series of wave and tide gauges, were deployed in the channel, along the reef crest north and south of the channel, within the lagoon and offshore (not shown). Significant wave heights H_S were computed by transforming the raw pressure data collected by both the current meters and wave gauges using linear wave theory.

Hourly Eulerian current time-series U_E were obtained from each current meter by averaging all samples in a burst, and were then rotated onto the principal component axes of the velocity variance. Wave setup distributions $\bar{\eta}$ were computed from the raw pressure data following Raubenheimer et al. (2001), using a reference level site on the forereef prior to breaking where we assumed $\bar{\eta} = 0$, i.e. wave setdown is estimated to be small here.

A preliminary 2D coupled wave-circulation numerical model was developed for the region surrounding Sandy Bay using

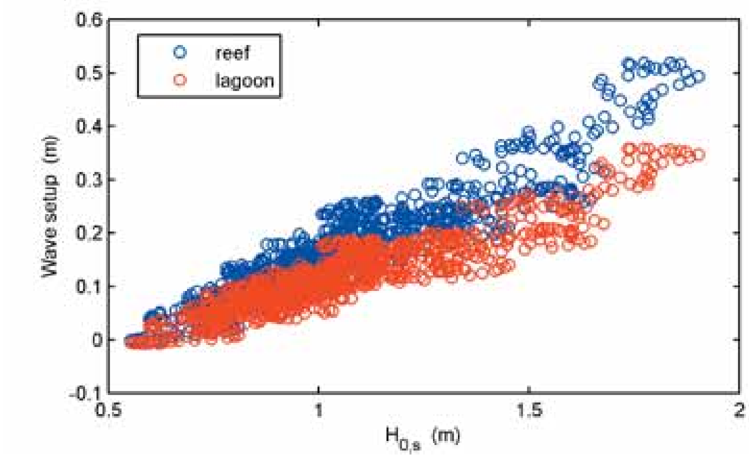

Figure 3.

Wave setup as a function of offshore significant wave height, measured near the reef crest and within the lagoon for the northern reef section.

Delft3D. Anticipating that the wave-driven flows in this system will be strongly dependent on the fine-scale [O(10 m)] spatial variations in reef bathymetry, for this modeling we incorporated high-resolution bathymetry derived from hyperspectral imagery (horizontal resolution = 3.5 m; depth rms error ~ 10%). The model domain extended ~20 km alongshore by ~8 km in the cross-shore with a nominal ~20 m grid resolution. The wave model (SWAN) was forced at the offshore boundary using directional wave conditions during the experiment, measured by a Nortek AWAC deployed on the forereef. The iteratively-coupled Delft3D-FLOW module was forced at the open boundaries using measured tidal harmonics with wind-forcing applied using data obtained from a weather station operated by AIMS, located on the coast ~20 km north of the study site.

Current findings and implications for management

During the experiment, the mean tidal amplitude was ~0.3 m, offshore significant wave heights ranged from 0.5 to 2.0 m, and winds varied between 2-6 m/s, coming mostly from the southwest. Analysis of the depth-averaged currents at sites along the reef crest and within the channel, revealed a dominant shoreward flow averaging 10-20 cm/s directed across the shallow (<2 m deep) reef with a return flow out the deeper channel (Figure 2a). The strength of these flows were strongly correlated with offshore significant wave heights (*R~0.8-0.9*), indicating that wave breaking was the dominant forcing mechanism driving the circulation of this section of Ningaloo (Figure 2b-d). Cross-reef currents along the southern reef section were typically ~50% faster than measured across the northern reef section (Figure 2b,d).

Measured wave setup, shown for two representative sites on the reef and within the lagoon (Figure 3), indicate that maximum setup near the reef crest varies from ~0 for $H_{0,s}<0.7$ to as large as 0.5 m when $H_{0,s}\sim 2$ m. Interestingly, the lagoon also sets up dramatically, with typical values ranging from 60-80% of observed maximum reef values. The relatively large lagoon setup observed on this fringing reef is thus very different from what occurs within the expansive (unbounded) lagoons of atolls and barrier reefs, where the mean lagoon water level is typically the same as offshore. Such lagoon setup must be present in Ningaloo (and other fringing reefs) to provide a pressure gradient to overcome the frictional resistance as water is driven back to the ocean through the relatively shallow and rough lagoon and channel of this system. By significantly reducing the cross-reef mean water level gradients, the wave-driven flows on Ningaloo are much weaker than currents typically observed on atolls and barrier reefs for the same range of incident wave conditions (see Gourlay and Colleter 2005 for a review). Despite these fairly weak flows, the flushing time of the lagoon (inferred from the total lagoon volume and cross-reef transport) is still relatively fast (5-8 hours).

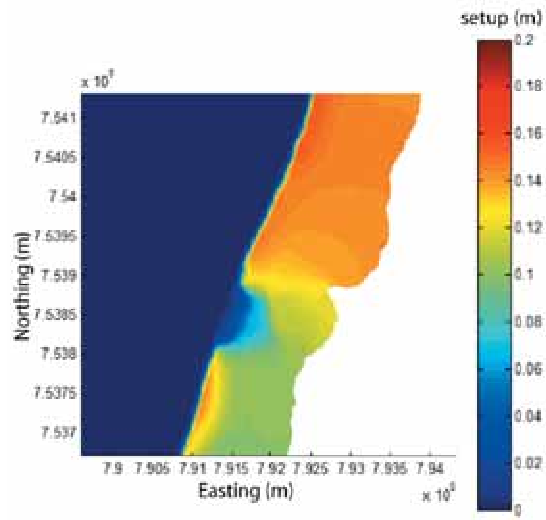

Figure 4.

Modeled time-averaged wave setup field.

Preliminary numerical simulations of the 2006 experiment period, indicate good agreement between observed and modeled current speeds and directions, albeit with some overprediction in the strength of the wave-driven flows (not shown, to be discussed). Notably, the model also predicts much weaker cross-reef currents over the northern reef section. The modeled 2D setup field (averaged over the simulation period) reveals a high degree of spatial variability (Figure 4). In particular, lagoon setup within the much shallower northern lagoon is, on average, much greater than within the deeper southern lagoon, thus elucidating why cross-reef currents measured on the northern reef section are so much weaker. In general, the momentum balance on the lagoon-channel return flow clearly plays a dominant role in controlling the magnitude of the wave-driven flows on fringing reefs; this momentum balance has typically been neglected in existing analytical model of reef wave-driven circulation.

Knowledge transfer

This research is highly relevant to the natural resource management agencies in WA. This, and future planned models, will ultimately help to improve predictions of the transport of material (e.g. nutrients, contaminants, larvae, waterborne pests, etc.) within Ningaloo Marine Park, predictions upon which a variety of regulatory and management decisions can eventually be made, e.g. oil spill response and managing the safety of nearshore swimming and diving activities.

The information gathered in this study will be transmitted to relevant agencies through reports, publications and symposia presentations.

Acknowledgements

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The role of oceanographic processes in the trophic ecology of coral reefs: linking reef biodiversity and biogeochemistry

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Project description

High gross benthic productivity despite apparently low nutrient concentrations in reef waters was long viewed a paradox. Darwin originally proposed that reefs increase their productivity with rapid recycling of sparse nutrients. More recently, studies have begun to suggest that the productivity of reefs may be highly dependent on external nutrient supply, such as from the land or ocean. The majority of reef productivity studies have focused on the role and fluxes of dissolved nutrients; however, there is increasing evidence that suspended particles may play a significant role in reef trophodynamics.

Reef organisms are capable of removing a range of particles from the water column, with more recent studies underscoring the importance of smaller particles <100 Ìm, particularly the pico- and nano-plankton. However, quantitative estimates of the significance of particulate input in terms of fluxes of carbon and nitrogen (N) are few. Several studies have confirmed that under experimental conditions particulate N uptake may be as high as that of dissolved N. An importance of particulate N adds weight to the theory that heterotrophic feeding by reef organisms may play a significant role in energy budgets, calcification and resilience to stressors. Despite this, the dynamics of particles, including factors controlling their supply and incorporation into reef food webs has received little attention, making the ecological significance of heterotrophy, and by extension the biological oceanography of surrounding waters, difficult to quantify.

Here we examine the uptake of oceanic particles on a fringing reef and propose a concept for quantifying the area of ocean upon which reefs depend. The specific aims of the project were to:

- Examine particulate matter dynamics over a fringing reef, and by extension the links between coral reef systems and surrounding oceanographic processes.
- Determine the scales at which oceanographic and reef systems may interact through quantification of a "dynamic ocean catchment".
- Identify organisms most important in linking reefs with the surrounding ocean.

The study took place at Ningaloo Reef, Western Australia (WA) which is adjacent to markedly seasonal oceanographic conditions (Figure 1). During the winter: the coast is dominated by the poleward Leeuwin Current, a warm, low-salinity/ nutrient current that effectively suppresses upwelling along the coast. During the summer: strong winds drive coastal counter currents; the northward flow of the Ningaloo Current promotes upwelling adjacent to reef. Consistent

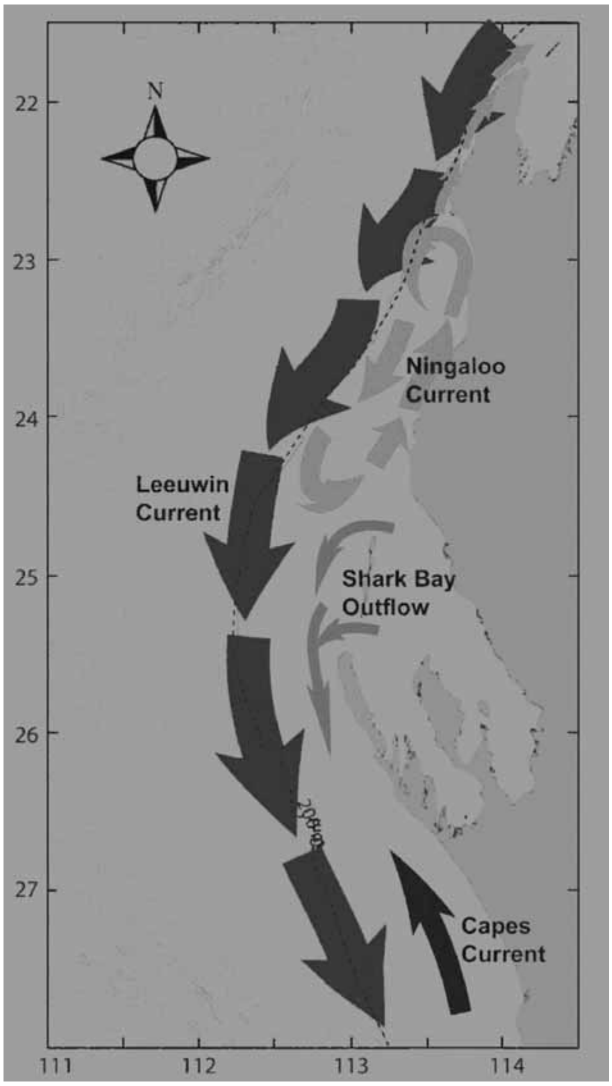


Figure 1.
Strongly seasonal oceanography off Ningaloo reef.

cross-reef flows over the reef are driven by wave set-up and are largely independent of tide and wind.

Current findings and their implications for management

Habitat-specific cross-reef phytoplankton depletion

GPS drifters were released shoreward of the surf zone to determine cross reef flow paths. This study found that Chlorophyll a (chl a) concentrations at Sandy Bay, Ningaloo Reef, markedly depleted along this wave-driven, cross-reef flow path (Figure 2). This reduction in chl a by more than a half was accompanied by chl a breakdown (phaeophytin, triangles) and occurred predominantly over the high cover reef flat community.

There was significant correlation between particulate nitrogen (PN) and chl a (r^2=0.232; $F_{[1,63]}$=18.982, p<0.01) (Figure 3). This relationship between PN and chl a allows PN contributed by photosynthetic particles to be estimated: chl a times a factor of 6.34 – 10.1. The estimated uptake of chl a represents a nitrogen flux to the reef of 5–17mmol Nm-2 day-1, an order of magnitude higher than typical rates for dissolved nitrogen, and confirms that particulate feeding on phytoplankton alone may be a major component of reef nitrogen budgets.

When there was an increase in oceanographic chl a adjacent to the reef the chl a was progressively absorbed by higher reef uptake rates, such that the internal reef chl a concentration always remained < 0.3 mg L-1 (Figure 4).

Habitat specific cross-reef phytoplankton depletion

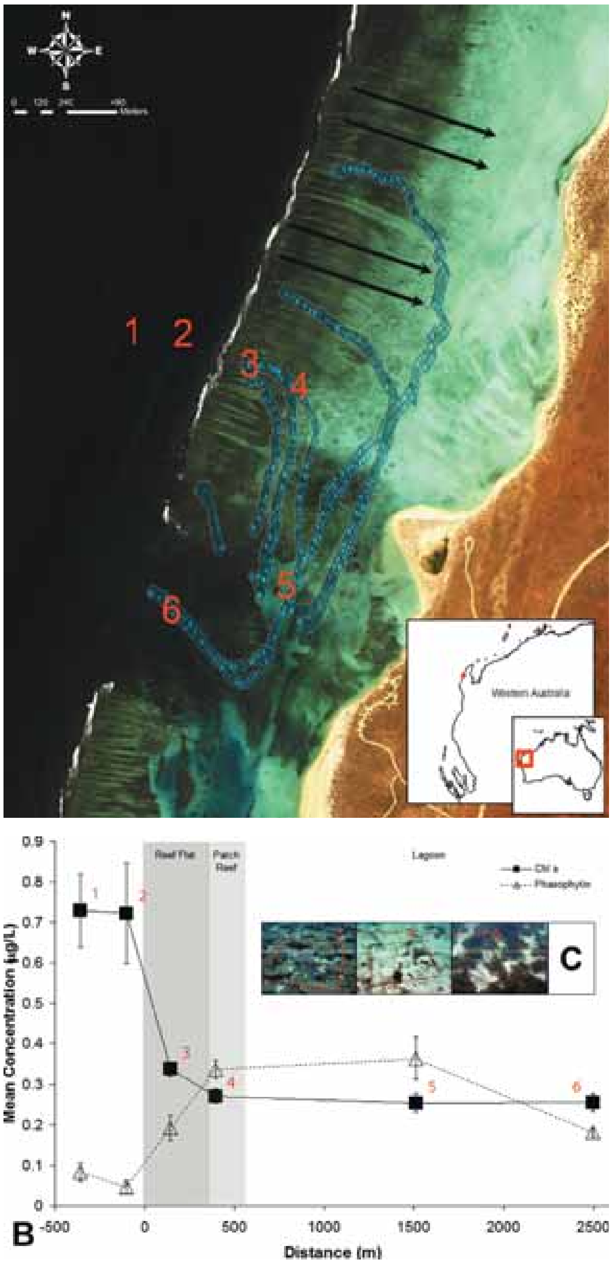


Figure 2.

(A) Plot of GPS drifters (blue tracks) released shoreward of the surf zone (black arrows indicate direction of flow). (B) Plot of the reduction in chl a (squares) over the reef flat. Numbers in red are sampling locations.

Dynamic ocean catchment ~6,000 – 12,000 km^2

The dynamic ocean catchment is estimated by:

- Uptake coefficient (S) [m day^{-1}]:

  S = St.v

Where:

Stanton number (St) is the ratio of uptake per unit area to the rate of advection of chl a past the reef

Velocity (v) is 0.10-0.20 ms^{-1} as measured during the study and consistent with previous measurements at the site

Uptake coefficient (S) of 16.8 – 33.7 m d^{-1} for the typical velocity range

- Uptake rate (m), [mg m^{-2} day^{-1}]:

  M = S.c

Where:

C is the concentration of chl a before crossing the reef averaged 0.7 mg m^{-3}

Uptake rate (m) of 11.8 – 23.6 mg m^{-2} day^{-1} for chl a

- Catchment area (A_c) [m^{-2} day^{-1}]:

$$A_c = \frac{m.A_r}{ch}$$

Where:

Ch is depth averaged chl a concentration offshore with an average of 20 mg m^{-3}

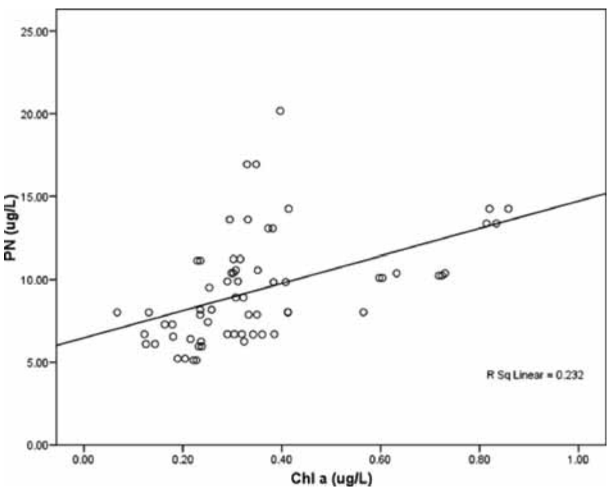


Figure 3.

Significant correlation between particulate nitrogen (PN) and chl a (r^2=0.232; $F_{[1,63]}$=18.982, p<0.01). Line is linear regression equation: PN = 8.23(chl a) + 1.89, standard error of slope 1.890.

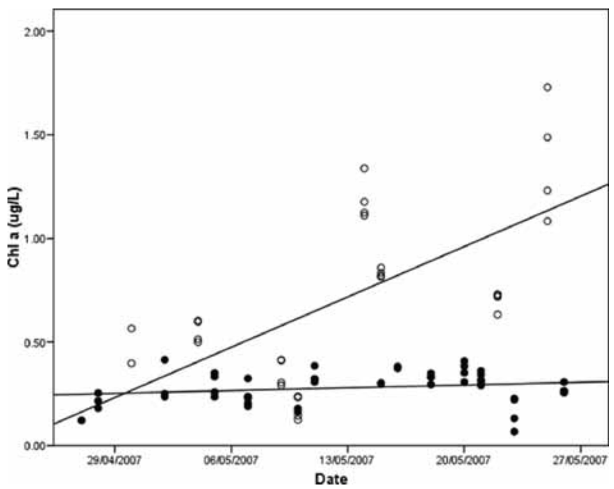


Figure 4.

*Increasing chl a adjacent to the reef, showing concentrations outside the reef (*open symbols 1&2 Fig 2) and inside the lagoon after passage over the reef (closed symbols, 3-6 in Fig 2). Lines denote linear regressions for outside and inside the reef, which were significant (r^2= 0.412; $F_{[1,28]}$=19.61, p<0.01) and non-significant (r_2=0.046; $F_{[1,47]}$=2.245, p=0.141), respectively.*

Finally, stable isotope signatures of nitrogen and carbon for Sandy Bay specimens showed potential evidence of two different food chains based on zooplankton (filter feeders and fishes) and phytoplankton (corals?) (Figure 5).

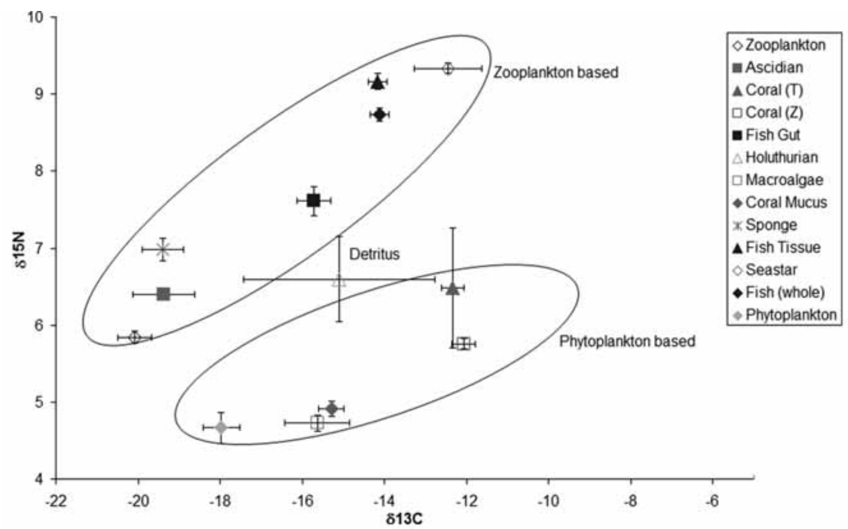
Overall this work raises several important issues for the biological oceanography and biogeochemistry for Ningaloo reef:

- Chlorophyll depletion demonstrates uptake of oceanic plankton by reef biota and scaling implies coupling to offshore oceanographic processes at a broad scale.
- Inputs of phytoplankton alone may represent a major component of reef nutrient fluxes and therefore offshore production a major functional component of reef biogeochemistry.
- Evidence of distinct zooplankton and phytoplankton based food chains on the reef has implications for the mechanisms and importance of oceanic plankton on a species-specific basis. Corals feeding on phytoplankton?

Dependence on a large ocean catchment for nutrient supply has implications for the susceptibility of reefs to global change. The potential indirect effects of climate change and ocean acidification on reef systems, such as through alteration of offshore currents and planktonic communities, require further consideration.

Figure 5.

*Stable isotopes of nitrogen and carbon (*δ15N and δ13C*) for Sandy Bay specimens. Note that location of coral mucus relative to coral animal tissue (Coral (T)), zooxanthellae (Coral (Z)) and phytoplankton.*



Cross-shelf transport and loss processes of primary production off Western Australia: the impacts of the Leeuwin Current on Ningaloo Reef

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Project description

Ningaloo Reef represents a hotspot of ecology, diversity and tourism resources. The Leeuwin Current (LC) may play a significant role in determining the offshore supply of nutrients and primary production (PP) to the Reef. Exactly how intra- and interannual variation of the LC impact the reef impact is unknown. How would a significant change in the PP available from oceanic sources impact the reef? To answer this we will quantify mechanisms governing the amount of offshore PP that crosses the shelf to contact the reef front, ultimately entering the Reef. This study will link process measurements of pelagic ecology at Ningaloo Reef (part of a larger reef-based study) with oceanographic assessment of pelagic processes and ecosystem carbon losses at a number of scales:

1) Based on a large-scale oceanographic study from Northwest Cape to Capes Naturaliste and Leeuwin off WA (May-June 2007), the gradients in relative production rates focusing on latitudinal gradients in processes driving carbon loss will be quantified: microzooplankton grazing, UV cell lysis and the impact of larger mesozooplankton on the food web.
2) Focusing on several transects off Ningaloo Reef from the same cruise we will execute a detailed analysis of the oceanographic linkages between the LC and the shelf adjacent to the reef, focusing on shelf-break gradients.
3) In a more detailed study of the shelf and reef front immediately adjacent to the reef, we will quantify pigment concentration, primary production, nutrient uptake. CTD (Conductivity-Temperature-Depth) profiles were also taken in order to describe the water masses.
4) I will contribute process understanding to a model of biogeochemical fluxes to and within Ningaloo Reef, which is being developed as part of a larger modeling effort associated with a newly developed hydrodynamic model. These modeling efforts include collaborations with international climate initiatives regarding the impact of climate change (including ocean acidification) on coral reefs worldwide.

Methods in Brief: For 1) and 2) we used data collected on the R/V Southern Surveyor during May/June 2007 off Western Australia. For 3), additional small-boat field work was executed on the shelf off Sandy Bay, Ningaloo Reef in May-June 2008 and includes: profiles of physical parameters, phytoplankton biomass, primary productivity measurements using C13 and N15, particulate organic carbon, particulate nitrogen, dissolved nutrients and nutrient uptake. These measurements have been made simultaneously with an intensive reef-based sampling program using similar methods.

Current findings and their implications for management

The preliminary analysis of the samples collected in May 2008 provides some innovative knowledge on the dynamics of the waters surrounding Ningaloo Reef. Sampling was done at nine stations, station 'a' being the closest to the reef and station 'g' being the furthest offshore (Figure 1).

The salinity profiles (Figure 2) indicate the presence of two water masses of different salinity. The existence of these two water masses suggests that the cross-shelf transport must be quite limited off Ningaloo Reef. Furthermore this also suggests that salinity is a suitable tracer of water masses for this region. The fact that the water further offshore has a higher salinity than the one inshore is quite unexpected as the Leeuwin Current transports warm, low salinity water.

From a biological perspective, the first day of our sampling in May 2008 showed us the existence of a high chlorophyll a layer at a longitude of ~113.72 in the surface layer (fig. 3). The concentration of chlorophyll a reached 1.2 µg/l which us much greater than what would be anticipated for this region. This bloom was dominated by phytoplankton >5 µm and High Performance Liquid Chromatography (HPLC) should enable us to determine the class of phytoplankton that dominated this bloom.

During the next few days of sampling this bloom seemed to disappear and highlight the importance of the temporal variability of these waters. This suggests that a regular sampling off Ningaloo Reef is necessary if we are to understand and further protect this hotspot of ecology, diversity and tourism resource.

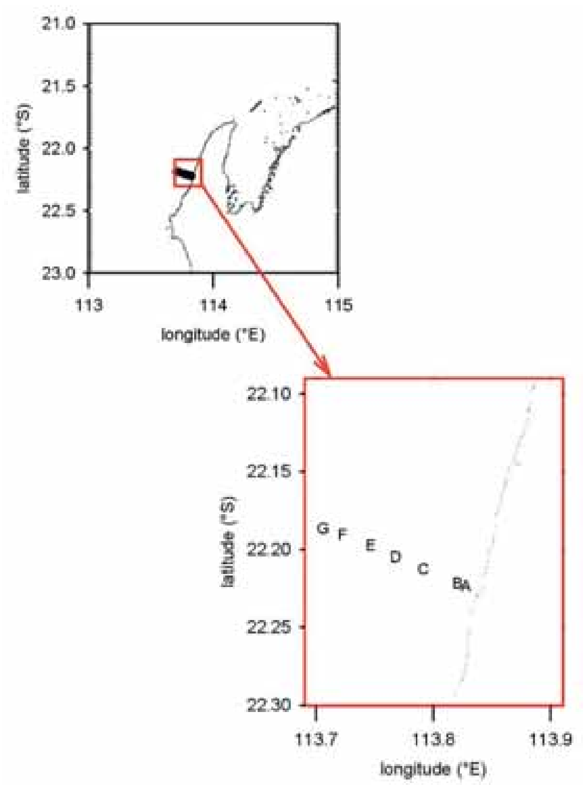


Figure 1.

Map of Ningaloo Reef showing sampling sites a (inshore) to g (offshore).

Knowledge transfer

Our novel combination will elucidate connectivity between the Leeuwin Current (LC) and Ningaloo Reef itself. Field work will allow us to parameterise key biogeochemical fluxes between reefs and surrounding oceans, for use in modeling applications such as Marine Strategy Evaluation (MSE) and other initiatives aimed at assessing the impacts of climate change. This includes the evaluation of the role of microbial processes in determining carbon dioxide fluxes, and UV-dependent carbon loss rates.

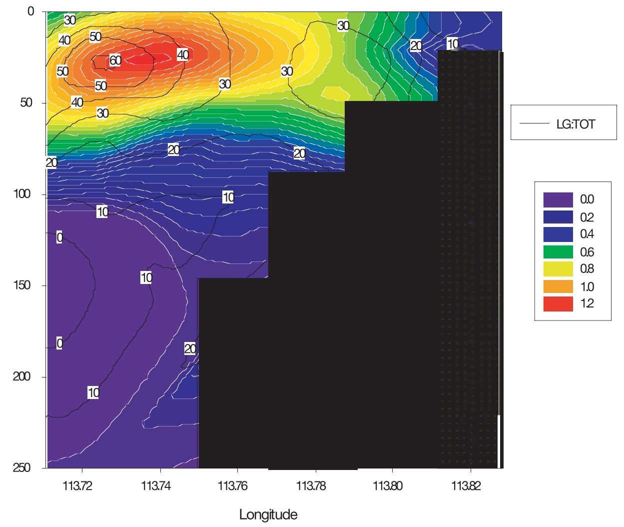


Figure 3.

Filled contour plot of the extracted chlorophyll a (in µg/l) and contour plot of the percentage of chlorophyll a >5 µm (May 2008).

Next stage

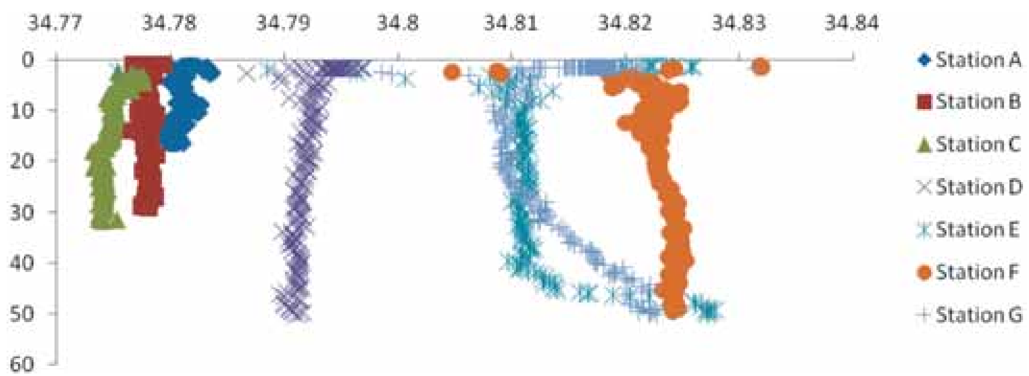
The next stage of this project will be to analyze the results for POC, PON, nutrient uptake and HPLC data. The sampling of these parameters will be repeated in November this year to describe the variation of cross-shelf transport intra-annually (strong Leeuwin Current in May vs. weak Leeuwin Current in November). Satellite data will then be used to put our field data into a larger temporal scale and observe the inter-annual variation. Finally we will see how this data fit into a hydrodynamic model off Ningaloo Reef developed by Greg Ivey and Ryan Lowe (UWA).

Acknowledgements

This research was supported by WAMSI, CSIRO, BHP-Billiton, UWA and ARC. Technical assistance was provided by Debbie Read and Saskia Heindrichs. We thank the captain and crew of the R/V *Southern Surveyor* and R/V *Linnaeus*.

Figure 2.

Salinity profiles of the surface waters off Ningaloo reef for station a to g (May 2008).



Modelling suggests connectivity between the Ningaloo Reef and coral reefs of the Pilbara

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Introduction

In the marine environment, the connections between isolated populations within biogeographical ranges of key sedentary marine species are important in terms of ecological stability. These species primarily comprise sessile benthic invertebrates such as coral and site specific reef associated demersal fish. Corals construct the structural framework for supporting and promoting biodiversity and complexity in coral reef systems (van Oppen & Gates 2006) and their ability to propagate and renew through a mobile planktonic larval phase is crucial to the maintenance of these ecological communities as well as their ability to recover after disturbance (Hughes et al. 2007). Connectivity between populations is mediated by the transport of eggs and/or planktonic larval phases within and between populations by ocean currents. Strong connectivity between regions may indicate that local populations may rely on upstream processes.

The current understanding of marine connectivity and its consequences has increased considerably over the last few years, inspired by its applications in fisheries management, marine reserve design introduced pests and the modelling of the effects of climate change (Cappo & Kelly 2001; Palumbi 2003; Mumby 2006; Underwood et al. 2006; Dorenbosch et al. 2007). Connectivity issues are also relevant to environmental management, especially to the assessment of secondary or downstream environmental impacts caused by marine and coastal developments (Roberts 1997; Palumbi 2003).

The level of connectivity between reefs is highly variable. Some may exchange eggs and larvae regularly resulting in genetically similar populations whereas others may exchange eggs and larvae on rare occasions. Further, recent research is providing some evidence that many reef populations, particularly fish species, can be effectively self seeding (Hughes et al. 2007). However, even occasional exchanges are important consequences for the long term sustainability and resilience of local populations (Lockwood et al. 2002).

The North West Shelf of Western Australia is remote and sparsely populated. It encompasses three marine parks: Montebello Islands Marine Park (MIMP), Barrow Island Marine Park (BIMP) and Ningaloo Marine Park (NMP) as well as Barrow Island and Muiron Islands marine management areas. There are also two proposed reserves at Dampier Archipelago and Cape Preston (Figure 1). The region is relatively free of human activity due to its remoteness and the frequency of tropical cyclones. However, in recent years the region has seen a surge in major oil and gas development applications due to the large subsea deposits of oil and natural gas, many involving substantial modifications to the local marine environments (e.g. Gorgon, Pluto). Consequently, there is an urgent need for informed environmental management of the North West Shelf region.

Physical oceanography

The Indian Ocean's eastern boundary current off Western Australia is atypical of other southern hemisphere continents as it is has pole-ward flowing coastal current transporting warm tropical water (Cresswell & Golding 1980; Pearce & Griffiths 1991). The Leeuwin Current dominates the Western Australian climate and the coastal marine environment and is characterised as being a large-scale, low salinity, oligotrophic current (Pearce 1991). It flows southwards to Cape Leeuwin, then eastwards towards the Great Australian Bight. The Leeuwin current is suggested to be generated from the Indonesian throughflow (Waite et al. 2007) and typically runs inshore and stronger during the Winter months when its effects may be experienced as far as Tasmania in El Nino years (Pearce & Pattiaratchi 1999). During the Summer months the Leeuwin Current is at its weakest and a counter current, the Ningaloo Current, becomes noticeable. The Ningaloo Current is a wind-driven northward-flowing nearshore current, running mainly between 22° and 24°S (Woo et al. 2006), however its cooler waters have been observed as far north as the Montebello Islands (21°S) (Figure 2).

The coral reefs systems

There are several major coral reef systems on the NW shelf: the Dampier Archipelago, Montebello Barrow Islands and Ningaloo Reef. The inshore east Pilbara Islands, though not extensive, comprises many small fringing coral reef communities.

The Dampier Archipelago region is characterised by a high diversity of corals and a wide range of physical and environmental conditions. The area of highest coral diversity and abundance occur in the clear waters on the seaward reef slopes of the outer Islands and shoals. Inshore coral communities tolerate high sediment deposition rates and

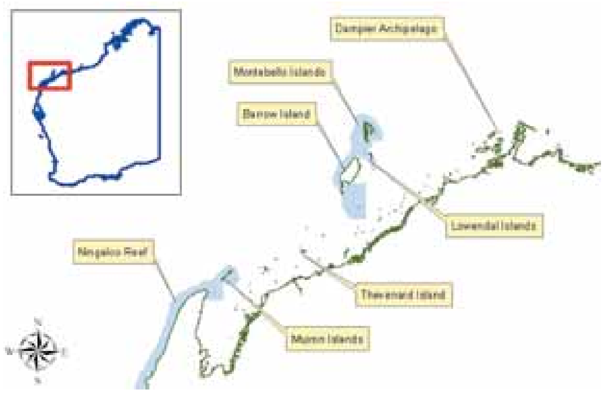

Figure 1.

Locality map: The Pilbara coral reefs.

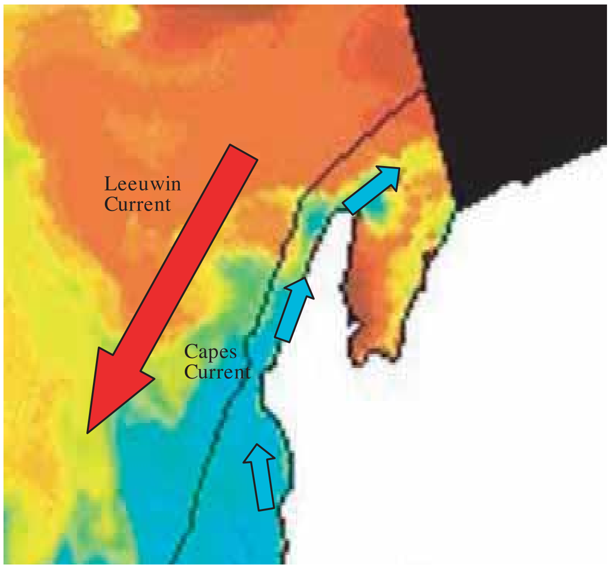

Figure 2.

Broad oceanographic influences:
the Leeuwin and Ningaloo Currents in November
(image courtesy A. Pearce).

highly turbid waters and are subsequently low in diversity and abundance (Osborne et al. 2000). A recent Study in the Dampier Archipelago revealed 229 coral, 275 sponge and 650 fish species (Jones D.S. (ed) 2004).

The Montebello/Barrow Islands marine protected area (MBIMPA) is an extensive coral reef system which is different to other coral reefs in Western Australia. While it contains some lagoonal areas and typical back reef assemblages (mainly tabular acroporids), the eastern reef system also includes networks of large *Porites* sp. colonies ("bommies") some of which are >4m in diameter and possibly >400 years old. This reef shows evidence of large scale disturbance, probably from the frequent cyclonic activity that the region is exposed to. As this is a relatively new MPA, effort has gone into the establishment of representative long-term benthic monitoring sites for coral community condition. Thus, we have information on a baseline quantitative assessment of the coral community and qualitative visual census of fish diversity and abundance (Bancroft in prep). The fish surveys identified a community of relative high diversity and abundance associated with the network of Porites bommies and suggests that they provide habitat for key reef fish species (Bancroft in prep).

Little is known about the coral distributions of the east Pilbara Islands. A recent survey undertaken at Thevenard and Surrier islands with the Australian Institute of Marine Science confirmed the presence of fringing coral reefs with low diversity and sparse densities, and clusters of *Porites* colonies of sizes ranging from 1 m to 4 m in diameter.

Ningaloo reef is the largest fringing barrier coral reef in the world and second to the Great Barrier Reef in Australia. The Ningaloo Marine Park and Muiron Islands Marine Management Area are characterised by a high diversity of hermatypic corals with at least 215 coral species recorded (Department of Environment and Conservation 2007).

Current findings and their management implications

The web-based Connectivity Interface (Connle) modelling tool, the precursor to the freely available Australian Connectivity Interface (Aus-Connle) described in (Condie et al. 2005), was used to explore the connective relationships between Ningaloo Reef and the coral reefs of the Pilbara. The Connle modelling tool (resolution = 0.1°) was developed as part of the North West Shelf Joint Environmental Management Study (NWSJEMS) and was designed to enable marine scientists and managers to investigate large scale patterns of larval dispersion and recruitment, and the development of scenarios and risk assessments for contaminant dispersion in the North West Shelf region (Condie et al. 2006). Specifically, it provides the user with an estimate of the probability that any two regions are connected by modelled ocean circulation over a specified dispersion period.

The Connle model was engaged to investigate two seasonal scenarios with 20 day dispersal time. A recent study in the Pilbara found that the corals of the Dampier Archipelago and Barrow Island have both autumn and spring spawning periods, the latter being the most significant (Rosser 2005; Rosser & Gilmour 2008). The first scenario investigated the fate of coral larvae if released from coral reefs in outer Dampier Archipelago, the Lowendal Shelf bommie fields and Dugong Reef in the MBIMPA, Thevenard Island and the Muiron Islands during an April spawning event. The Connle output (Figure 3) suggested that there may possibly be larvae transport from the Pilbara reserves to the Ningaloo Reef. It

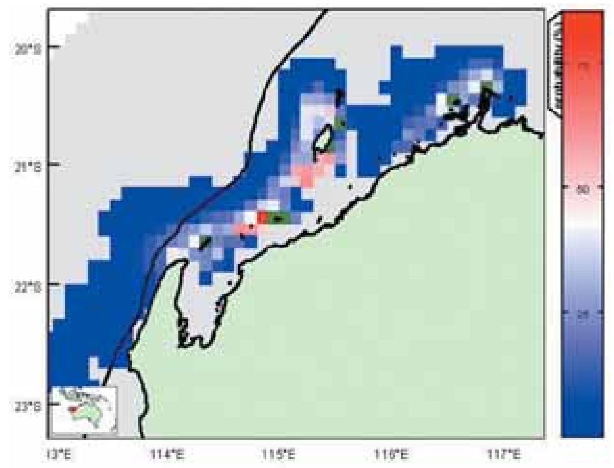

Figure 3.

Connectivity statistics for coral spawn sources indicated by the green squares, at the Dampier Archipelago, Dugong Reef, Lowendal Shelf bommies and Thevenard Island, after a 20d dispersion in April. (courtesy S Condie CSIRO)

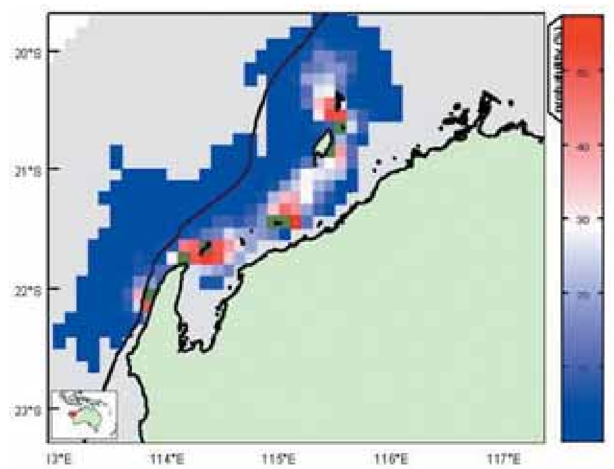

Figure 4.

Connectivity statistics for a fish eggs and larvae sources indicated by the green squares, at Tandibiddi, Pt Murat (Ningaloo), Muiron Islands, Thevenard Island, Dugong Reef and Lowendal Shelf bommies after a 20 day dispersion in November (courtesy S Condie CSIRO).

indicated a high probability that the MBIMPA would be a source of coral recruitment to Ningaloo via the west Pilbara offshore islands and the Muiron Islands. The model also suggested that the Dampier Archipelago may possibly be a source of coral recruitment to the inshore Pilbara islands and the MBIMPA, however as a recent study suggested, it may be over several generations (Underwood in revision). This genetic study of the broadcast spawning coral species *Acropora tenui*, suggested similarities between coral populations at Dampier Archipelago and Ningaloo Reef (Underwood in revision) thus supporting this first scenario.

A comprehensive review into the spawning of tropical reef finfish (Westera 2001), suggested that serranids were likely to spawn between September and December. The second scenario investigated the fate of finfish spawn and larvae if released during a November finfish spawning event for a 20 day dispersal from Tandibiddi and Pt Murat (Ningaloo), Muiron Islands, Thevenard Island, and Dugong Reef and the Lowendal Shelf bommie field (MBIMPA). The model suggested strong connective processes between Ningaloo Marine Park, the Muiron Islands, the west Pilbara Islands and the MBIMPA (Figure 4). Ningaloo Marine Park may possibly be an upstream source of some demersal fish recruitment to the coral reefs of the west Pilbara, and the Lowendal Shelf bommie field may be an upstream source for the Montebello Islands.

Implications for management

The Connle modelling suggests that there is some level of connectivity between coral reefs of the North West Shelf. This information will need to be taken into account with current and future development of the area. The Western Pilbara is a focus for oil and gas exploration and extraction, with many existing and proposed developments west off the Muiron Islands (eg. Enfield, Vincent/van Gough) and the west Pilbara Islands (eg. Thevenard, Barrow and Varanus). The Gorgon Gas Development, proposed for Barrow Island, alone is an enormous project, that will include a 3 year construction phase, construction of a 2.1 km solid causeway and a 2.1 km pylon jetty and the production of 7.6 million m3 of dredging spoil over an 18 month dredging program.

Given, the potential connectivity between areas within the region, new industrial developments such as the Gorgon Gas proposal, may have downstream effects on the level of coral recruitment to the inshore Pilbara and Ningaloo coral reef systems.

Physical and ecological issues such as connectivity that go beyond specific site impacts need to be considered when assessing development proposals in the region so that the possibility of long-term profound changes in downstream communities can be avoided and/or managed appropriately.

Knowledge transfer

This project is part of the research undertaken within the Marine Science Program of the Department of Environment and Conservation. The work in this program is made available to the DEC for relevant planning and management activities.

Next stage

The next step for this project will be to finalise a technical report entitled "*Long-term benthic community monitoring in the Montebello/Barrow Islands marine protected areas: Site descriptions and preliminary analysis*" that will present the baseline data for each site and recommendations to management and for future research.

The Marine Science Program will also continue to encourage and support further studies on the genetic connectivity of the Western Australian coral reef systems, particularly investigating broadcast spawning coral species.

Acknowledgements

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Summary of the 2006 winter coral bleaching event at Ningaloo Marine Park

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Abstract

Mass coral bleaching events triggered by anomalously high seawater temperatures have been reported worldwide with growing frequency over the past two decades. However, the impacts of low temperature coral bleaching on reefs are less frequently documented.

The first major coral bleaching event ever recorded for Ningaloo Reef occurred in winter (July) of 2006. The combination of cold air temperatures and aerial exposure of corals due to a low spring tide and a high pressure system appeared to cause bleaching of exposed corals. Submerged corals appeared to remain unbleached. Observations made during an aerial survey indicated that bleaching had occurred along most of the Ningaloo Reef. The most severe bleaching was recorded at Pelican Point, where approximately 81% of live hard coral was bleached. Bleaching was restricted to shallow-water corals of back-reef and patch reef environments dominated by plate and corymbose acroporids. To investigate the recovery of bleached corals, two surveys were undertaken at Coral Bay and Pelican Point. At Coral Bay, approximately 90% of bleached coral had recovered by 14 weeks after the event, and approximately 100% of bleached coral had recovered at Pelican Point 30 weeks after the event. Other field observations suggest reef-wide recovery.

The possibility that Ningaloo Reef may be less likely to be affected by bleaching than reefs elsewhere in the world, whether through intrinsic factors, or because local oceanography buffers the reef from extreme temperature changes, is important. It places even greater emphasis on the need for careful conservation management to maintain Ningaloo Reef as a coral reef refuge and reference site of local, regional and international significance.

Project description

The overall objective of the surveys was to quantify the spatial extent and severity of bleaching and associated recovery of corals from the 2006 winter bleaching event at Ningaloo Marine Park (NMP) and the Muiron Islands Marine Management Area (MIMMA). An aerial survey was undertaken to record the spatial extent of bleaching on a reef-wide scale. Information on the proportion of live hard coral that was bleached was collected at nine locations at NMP and the MIMMA approximately 5 weeks after the event during the 2006 Drupella survey. The location that was most affected by bleaching (Pelican Point) was re-surveyed 30 weeks after the event to investigate coral recovery. The recovery of corals was also monitored 1, 2, and 14 weeks after the event at four patch reef sites at Coral Bay.

Figure 1.
Bleached back-reef corals.

Figure 2.
Bleached patch-reef corals.

Corals were surveyed along one 20 m transect per patch reef at Coral Bay using video transect techniques. See the Drupella monitoring project summary (Armstrong 2008, this volume) for a description of the methods used to survey corals at the nine locations in 2006 and when re-surveying corals at Pelican Point in 2007.

Current findings and their implications for management

During the aerial survey, coral bleaching was observed from Tantabiddi to Gnarraloo Bay. Bleaching was observed to be patchy and restricted to corals in shallow water, usually on back-reef areas (Fig 1) and also on the tops of some patch-reefs (Fig 2).

Bleaching of corals was recorded at all six shallow back-reef locations during the Drupella survey (Fig 3). No bleaching was recorded at the remaining three locations (Three Mile, North Muiron, or South Muiron), where corals are deeper, and were likely to have been submerged during the bleaching event. The highest proportion of bleached coral was recorded at Pelican Point, where 81.4% (+ 4.54) of live hard coral was bleached. Plate Acropora dominated coral cover at Pelican Point.

Results from the Pelican Point survey indicated 100% recovery of corals by 30 weeks after the event (Fig 4). Qualitative field observations made since the bleaching event at various other locations along NMP also indicated 100% recovery of corals from bleaching.

Results form the Coral Bay survey indicated that the shallow reef top corals recovered from bleaching over a three month period. Around 52.2 % (+ 8.66) of corals were bleached one week after the event. Bleached coral declined to 30.2 % (+ 8.51) after two weeks, and 4.92 % (+ 3.96) after 14 weeks (Fig 5).

No coral bleaching was observed in 2007, despite similar cold air temperatures ocurring during low spring tides. Further research is needed to identify factors that cause bleaching due to aerial exposure and cold temperatures and to understand the effect of their interaction.

Although the number of regions reporting mass coral bleaching has increased substantially in recent years, this is the first temperature related coral bleaching event to ever be recorded at Ningaloo Reef. Unusually (in global terms), almost 100% recovery was observed. The reasons for Ningaloo Reef's apparent resistance to bleaching are unknown.

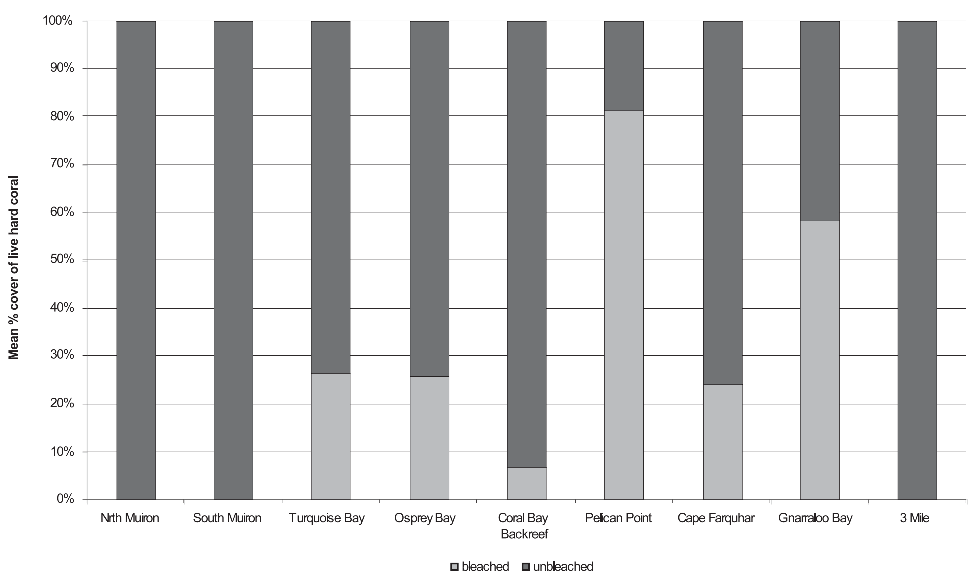
It has been hypothesized that the predominant currents that influence Ningaloo Reef, the south flowing Leeuwin Current and north flowing Ningaloo Current, interact in a manner that buffers corals from sea temperature abnormalities. In addition, Ningaloo Reef may be less vulnerable to warm water bleaching due to prevailing effects of the cooling sea breeze during the summer months.

The fact that Ningaloo Reef is well-flushed might also be a significant factor that helps decrease the ranges in sea water temperature. The areas of the Great Barrier Reef that have suffered repeated bleaching impacts due to high sea water temperatures are mostly inshore, where waters can pond and remain very still for days, heating very rapidly beyond thresholds for bleaching.

Temperatures from offshore Ningaloo increased by about 0.6°C in the recent decades, and there appears to have been a shift in seasonal cycle. The highest temperature is now observed in April instead of March as in previous decades. A similar trend could be observed in other coastal areas and inferred from skeletal isotope measurements at coral reefs. It is possible that the warming of sea surface temperatures off

Figure 3.

Proportion of live hard coral that was bleached and unbleached at the nine locations surveyed during the 2006 Drupella *survey. Totals equal mean (n = 9 transects per location) percent cover of live hard coral.*



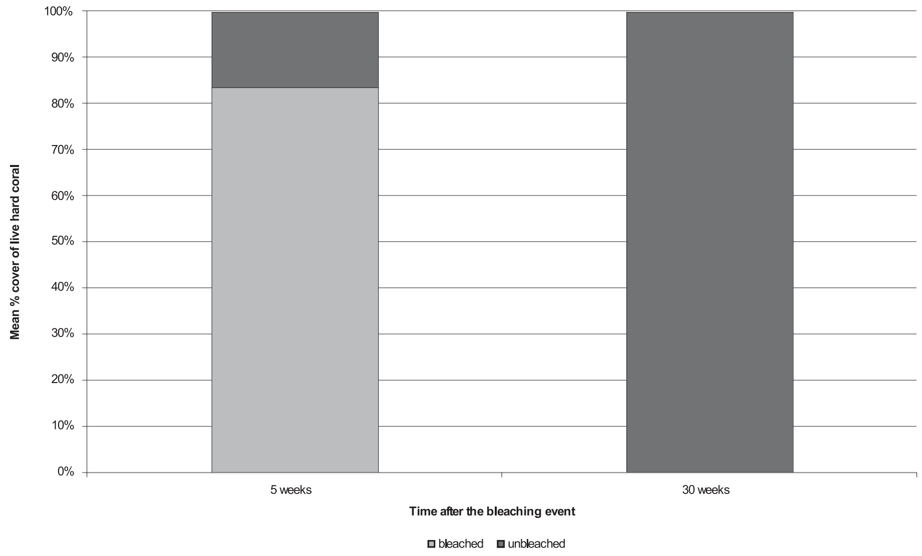


Figure 4.

Proportion of live hard coral that was bleached and unbleached at Pelican Point approximately 5 weeks and 30 weeks after the bleaching event. Totals equal mean (n = 9 transects) percent cover of live hard coral. There was no significant difference in total live hard coral cover between the two survey times (p = 0.82).

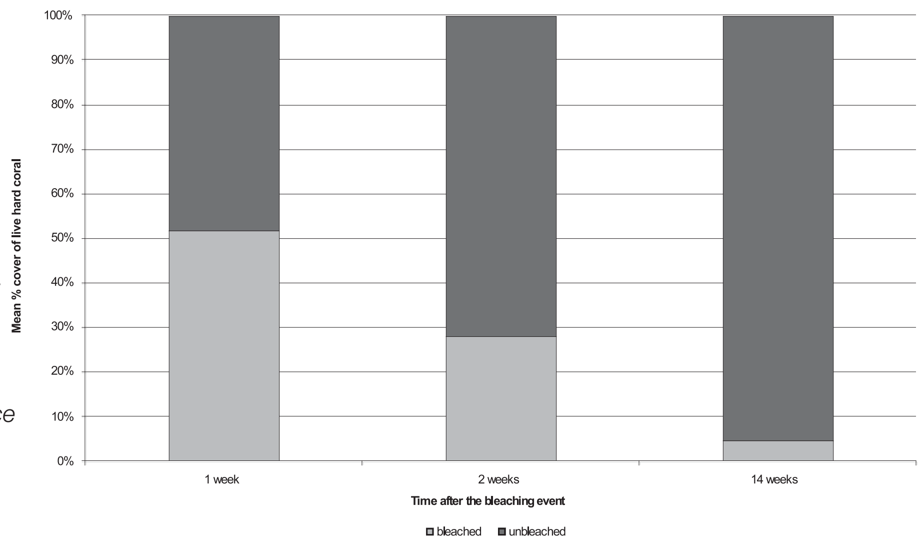


Figure 5.

Recovery of corals indicated by the proportion of live hard coral cover that was bleached or unbleached at Coral Bay approximately 1, 2 and 14 weeks after the bleaching event. Totals equal mean (n = 4 transects) percent cover of live hard coral. There was no significant difference in total live hard coral cover between three survey times (p = 0.90).

Ningaloo may increase the likelihood of summer bleaching. Further research is needed to determine whether changes in offshore sea surface temperatures affect the temperature of waters bathing Ningaloo Reef.

Knowledge transfer

This study has provided planning and operational management with a better understanding of the effect of bleaching due to aerial exposure and cold temperatures on the coral communities (KPI) at NMP. The fact that this was the first, and so far the only, major bleaching event to be recorded at Ningaloo Reef, highlights the possibility that Ningaloo Reef may be less susceptible to bleaching than other reefs worldwide. This possibility underlines the need for effective conservation management of Ningaloo Reef. This research contributes to scientific knowledge concerning: 1) tolerances of the coral-zooxanthellae symbiosis to low temperature aerial exposure, 2) recovery of corals from this type of bleaching event.

Next stage

It is recommended that the Department of Environment and Conservation develop a Coral Bleaching Response Plan for Western Australia. The plan should include the following elements:

a) a system to forecast coral bleaching events;

b) early warnings of coral bleaching events;

c) measure the spatial extent and severity of any major coral bleaching event;

d) assess the ecological impacts of mass coral bleaching;

e) communicate and raise awareness about coral bleaching and climate change impacts on Western Australian reefs; and

f) set up management actions that could reduce severity and increase chances of recovery from bleaching events.

The prediction of coral bleaching events and increasing our understanding about the factors that contribute to bleaching and how they interact could be achieved by:

a) monitoring weather conditions that are conducive to anomalous sea water temperatures;

b) sea and air temperature monitoring;

c) reporting any early signs of bleaching on reefs; and

d) recording the spatial extent and severity of any bleaching and subsequent recovery.

It is strongly recommended that temperature loggers be deployed at several sites along Ningaloo Reef (both inside and outside the reef lagoon) and other Western Australian coral reefs as soon as possible. The range of sea water temperatures that Ningaloo Reef corals are routinely exposed to could then be determined. Combined with the parallel reporting of bleaching events, these data could then be used to provide future early warning predictions of when and where bleaching is likely to occur.

Acknowledgements

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Socioeconomics and human use

High resolution mapping of reef utilisation by humans in Ningaloo Marine Park

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This project forms part of the Wealth from Oceans Flagship Ningaloo Collaboration Cluster. The main objectives are (1) to determine the spatial and temporal distribution of recreational activities (e.g., fishing, diving, snorkelling, kayaking, surfing etc) within the reef lagoon system at Ningaloo Marine Park (NMP) and (2) to relate distribution patterns to factors such as biodiversity, physical conditions, park zoning, access roads and accommodation nodes.

During 2007, intensive field work, based out of Exmouth, was conducted throughout the year. Aerial and land-based coastal surveys covered the entire 300 km length of the NMP and type and location of all shore-based recreational activity and boating activity in the lagoon were recorded in a geo-referenced format for input into a Geographical Information System. Land-based coastal surveys, conducted using a four wheel drive vehicle, were split into three areas: Exmouth to Yardie Creek, Yardie Creek to Coral Bay and Coral Bay to Red Bluff. These land-based surveys also provided the opportunity for researchers to interview people engaged in recreational activities in the NMP in order to obtain information on demographics, trip duration, travel and site-specific usage patterns, other activities conducted in the NMP as well as catch and effort by recreational fishers (to supplement the Department of Fisheries Gascoyne creel survey).

All data from the aerial surveys have been entered into an Access database and validated. In total, 34 aerial surveys were conducted following a stratified sampling design whereby more flights were conducted during the winter months. From these flights, "snapshots" of activity with regard to location of boats, camps, vehicles and people along the coast have been obtained and they clearly highlight nodes of activity and the winter increase in usage of the NMP. In total, 2 884 observations of boats and 4 770 observations of shore-based activity were made on these flights. These data, although more comprehensive, are comparable with aerial counts of camping at Ningaloo that have been conducted over the past decade by staff of the DEC district office in Exmouth. Over the next year, work will focus on analysis and interpretation of these geo-referenced data.

Equal numbers of land-based coastal surveys were conducted during each month of 2007 (n=192 days of field work). The data from these surveys have also been entered into an Access database and validated. These surveys enabled greater resolution with respect to the specific activities conducted by people in the marine park, especially the lagoonal areas where diffuse access by the many people camping along the shore has not been spatially explicit in the past. Once again, the clear seasonal pattern in use of the park was evident, particularly the sustained usage over the winter months between April and October. In total, 7 889 observations of shore and boat-based activities were made. In terms of observations of boats per month these ranged from 75 in January to 359 in August and for shore-based activities the range was from 133 observations in March to 861 observations in July. Altogether, 25 655 people were recorded as participating in shore-based recreational/tourist activities in the NMP during the study period. Of these, 32% were relaxing on the beaches, 11% snorkelling, 8% shore-fishing and 7% swimming. Spatial and temporal analyses of these data are underway in line with the objectives of the project.

Indicators that can be used by managers to easily monitor usage of the NMP will be explored (e.g. number of cars in car parks like Turquoise Bay relative to number of people engaged in activities at the locality). In addition, during the design and implementation of the coastal surveys, compatibility with existing DEC compliance protocols was taken into account so that the high resolution dataset can complement current DEC monitoring activities.

During the coastal surveys, 1208 face-to-face interviews with users of the NMP were conducted. Locations of interviews were spread throughout the NMP although their distribution was proportional to the relative abundance of users in the different parts of the park. The fine-scale resolution and geo-referenced nature of this dataset makes it particularly pertinent to site-specific planning and management of Ningaloo Reef and the adjacent coastline.

The majority of interviewees were from Western Australia (62%), particularly the Perth metropolitan area. International visitors and interstate visitors comprised 23% and 14% of interviewees, respectively. Over half of the interviewees had visited the NMP on a previous occasion, and 43% of these indicated that they always stayed at the same location, indicating strong site loyalty. Though visitors to the region were most likely to have visited the NMP less than twice in the previous 12 months, most of the local residents of Exmouth that were interviewed indicated that they had visited the NMP from 10 – 100 times in the previous year.

The most popular types of accommodation for visitors were caravan parks and wilderness camping, with the average length of stay 15 days.

There were > 50 different types of activity being undertaken at the time of the interviews though, as with the land-based surveys, relaxing on the beach, shore fishing, beach walking and snorkelling were most popular. The mean length of time spent at the beach during a day trip was 3.1 hours and interviewees had participated in an average of three different activities (range of 1 – 10 activities) during their stay. The home range of visitors from beach access points was small and clustered around these locations.

Activities at three popular beaches (Coral Bay, Turquoise Bay and Bundegi Beach) were monitored from early morning to evening during the 2007 Easter and July school holidays to establish the diurnal pattern of usage with regard to beach activities, boat launching and tourist operations. These data formed part of an MSc thesis and will be used to scale and contextualise observational data from the overall project relative to time of day.

During 2007, some waterproof oceanographic trackers that can be attached to recreational and tourist vessels to map routes and determine the spatial footprint of various activities at Ningaloo were manufactured. These were tested on tourist and research vessels and satisfactory tracking was obtained. During 2008 this aspect of the project will be expanded.

Overall, the Ningaloo human usage mapping project is on schedule and the results will contribute directly to the integrated ecosystem model being developed for the Ningaloo region through the Collaboration Cluster. It is expected that the quantitative information from the human use mapping project will have the required spatial and temporal resolution to assist managers with predicting the likely consequences of future coastal development and changes in management regimes in the region.

Tourism futures for the Ningaloo region: development of a destination model

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Abstract

The twin goals of the Ningaloo Destination and Data Modelling (NDDM) project are: to develop a dynamic model of Ningaloo incorporating socio-economic, and load implications of tourism that can be integrated with an ecological model of the region; and to effectively engage with stakeholders to build both trust in the model and group learning between researchers and stakeholders with respect to regional tourism planning and governance. Drawing its methodology from mediated modelling, which developed within learning organisations theory, and sustainable tourism planning, the NDDM project is engaging with stakeholders through public workshops, meetings and disseminating information through newsletters and the regional media. The finished model will be used by regional managers (in particular DEC, DPI and the Shires) to input into land and resource use decisions and by all stakeholders including community groups, the shires and the tourism industry, to collaboratively assess and discuss tourism planning in the region. The NDDM project is gathering primary data through surveys of visitors, residents and accommodation providers, and is engaging with other research projects, industries, and public agencies to gather and share secondary data. To date, the three most significant research outcomes are: four collated tourism scenarios for the region; the results of initial visitors surveys; and an early prototype of the Ningaloo Destination Model, that assesses the effects of changing the visitor mix on activities and accommodation demand in different subregions.

Project description

The goal of Ningaloo Collaboration Cluster Project 3 (also called the Ningaloo Destination and Data Modelling (NDDM) Project) stated in its research plan is to develop a dynamic model of Ningaloo incorporating socio-economic, and load implications of tourism that can be integrated with an ecological model of the region. However, a completed tourism destination model requires a second important outcome. The NDDM project is building relationships with stakeholders to ensure that it promotes group learning amongst stakeholders and researchers, that the model is relevant to stakeholder needs and that the model will continue to be used into the future. The twin goals of gathering the knowledge to build a destination model that incorporates the environmental, economic and social impacts of tourism and effectively engaging with stakeholders have shaped the project's methods and design.

The NDDM project was fashioned through an engagement between the CSIRO's Wealth from Ocean's Flagship and the Sustainable Tourism Cooperative Research Centre (STCRC). The NDDM project makes use of collaborative links with other universities and CSIRO, both when drawing on research expertise and when sharing data. The methodology for the project builds on previous STCRC destination modelling projects and makes use of tourism research tools and techniques generated through previous STCRC projects. The methodology employed draws from mediated modelling techniques developed through learning organisations theory (closely related to system dynamics), and sustainable tourism planning. Mediated modelling uses participatory research approaches to implement collective learning processes (Senge, 1990; van den Belt, 2004). The development of a computer model to support reflective stakeholder engagement through simulating issues within a complex system is an important tool for group learning and the model is a central outcome of the project.

Tourism is 'an inherently complex and dynamic system' (McKercher, 1999), which aligns it with the search for methodologies to deal with complex problems in sustainable development research (Hadorn, Bradley, Pohl, Rist, & Wiesmann, 2006). Another similarity with sustainable development is that tourism planning research increasingly has the primary objective of contributing to providing lasting and secure livelihoods which minimise resource depletion, environmental degradation, cultural disruption and social instability (Hall, 2000). The path to sustainability when dealing with complex problems that involve both social and scientific elements is increasingly recognised to be through a transition and learning process involving stakeholders and researchers that is transdisciplinary in breadth and issue focussed (Farrell & Twining-Ward, 2005; Hadorn et al., 2006; Wickson, Carew, & Russell, 2006). As such the NDDM project requires a methodology that reflects the diversity, complexity and dynamics of tourism, while engaging with stakeholders to ensure their participation and mutual learning. Mediated modelling provides a methodology that brings together research in a number of disciplines, focuses research on issues that are collaboratively defined as important by stakeholders and researchers, and provides for continuous stakeholder engagement.

The project design reflects the needs for stakeholder and researcher participation and data collection. Through three stakeholder workshops in the Ningaloo coastal region, stakeholders identified ten tourism scenarios that encapsulated what they wanted and did not want out of tourism. A scenario was defined as a story about a possible future. The ten scenarios were refined to four in order to eliminate overlapping scenarios from different regions (see table 1). Researchers and stakeholders also met in the region for a two day workshop in Exmouth to examine the dynamics of tourism in the region. Nine tourism 'sub-models' were discussed in the workshop, where participants identified the variables and dynamics for different aspects of the tourism system. Participants also drew links between the submodels, which together constituted a conceptual model of tourism in the region. This model is informing the development of the Ningaloo Destination Model. Feedback on the model and further refinement of the scenarios is occurring through ongoing workshops, the second round of which was held in May.

Required data and possible data sources were identified both during and after the initial workshops. Visitor surveys are an important source of data. Visitor surveys will be run over 18 months at three monthly intervals, both during and outside school holidays. We have designed and distributed a second survey assessing environmental load within different accommodation types in order to quantify the amount of water and electricity used and waste water generated. We are also assessing the impacts of coastal tourism on the terrestrial environment and the reef from tourists' activities and camping. We have administered a third survey of resident's perceptions of tourism designed by Liz Fredline from Griffith University and Margaret Deery from Victoria University in Exmouth and Coral Bay. The response rate was good in both locations, with over 20 percent of households completing the survey. We plan to administer the survey in Carnarvon. Data has also been generously provided by the Department of Environment and Conservation, the Water Corporation, and Tourism WA.

Current findings

To date, the most critical current findings for stakeholders and involved researchers are the four scenarios, visitor survey data, and the prototype of the Ningaloo Destination Model. The four tourism scenarios address questions of growth, governance and the introduction of green technologies and development strategies. There were differences amongst the towns, with Exmouth more focussed on green technologies, Carnarvon more focussed on development priorities, and Exmouth and Coral Bay more oriented towards governance questions, in particular related to the tourism operators who relied on licenses and development regulations. The Ningaloo

Table 1.

The Four Consolidated Tourism Scenarios

The Four Consolidated Tourism Scenarios
Scenario 1: A large increase in visitor numbers versus a controlled increase. This scenario addresses questions for increased growth – if you can control growth in particular segments (in particular those who prefer a particular accommodation type and activities with differing environmental impacts), what will be the costs and benefits over the longer term to the environment, the community and the economy?
Scenario 2: Changes to Governance This scenario addresses questions about governance raised in particular in Exmouth and Coral Bay. If there are changes in governance over accommodation and activities, what will be the impacts on tourism? Will they be substantial or minor? Particular concerns were over license tenure and land release (zoning).
Scenario 3: Varied rates and uncertainties of growth This scenario addresses a second aspect of growth. What if there are unexpected interruptions? What are the best strategies for a fast recovery following an unexpected event or variations in visitor numbers to the region? The view also addresses the issue of capacity constraints by testing a variety of land release policies.
Scenario 4: Green technologies and development strategies in the town centres The fourth scenario addresses how adoption of green technologies could affect the capacities of the town sites to expand in the short, medium and long term, given current constraints on water, electricity and waste water, and the spatial allocation of tourists. It also addresses the costs and savings over different time periods. Climate change will also be examined within this scenario.

Table 2.

Ningaloo Coast Visitor Data.

Ningaloo Coast Visitor Data

Accommodation Type	Count	Column %
Campsite	187	39.2
Caravan Park	323	67.7
Backpackers	56	11.7
Hotel / motel	74	15.5
Rental home / unit / apt	35	7.1
Visitor Origin	**Count**	**Percent**
West Australian	267	52.4
Interstate	126	24.7
International	117	22.9
Activities Undertaken	**Count**	**Column %**
Sightseeing	373	73.6
Snorkelling	347	68.4
Shopping	320	63.1
Laying on beach	312	61.5
Eating out	301	59.4
Activities rated as important or very important	**Count**	**Column %**
Snorkelling	262	56.3
Sightseeing	236	50.8
Fishing from shore	131	28.2
Laying on beach	113	24.3
Camping	111	23.9
Elements of Trip rated as important or very important	**Count**	**Column %**
Natural environment	443	87.4
Region's warm weather	389	76.7
Access to Ningaloo reef	352	69.4
Getting away from it all	332	65.5
Camping facilities	266	52.5

Destination Model will need to be able to address these scenarios, while providing a measure of their likely social, economic and environmental consequences.

The visitor survey results presented here in Table 2 are from surveys conducted in July and October 2007. Further surveys have been completed in February and April 2008, and are currently being processed. Not surprisingly, most visitors to the region stayed in caravan parks, and over 50% of all respondents were from Western Australia. Snorkelling and sightseeing were the two most popular activities, and were both rated well above fishing from the shore in importance by visitors. Only 5% of international visitors rated fishing from the shore as important, which compares to 37% of Western Australians and 29% of interstate visitors. The natural environment was the most important element of the trip, followed by the region's warm weather.

The prototype destination model at its current stage provides an indication of how changes in the visitor mix will impact on activities and demand for different accommodation types in different subregions along the coastline. For example, a change in Exmouth has implications for activities on the Northwest Cape and in Cape Range National Park. If the amount of Australian families were to increase, there would be increasing numbers of people on the beaches in the national park. If older Australian caravanners were to increase, there would be little change in the amount of people on the beaches, but a large increase in the fishing load in the gulf and the marine parks. The finished model will also provide indications of changing social, economic, environmental load and environmental impacts, providing a holistic method of assessing possible changes.

Knowledge transfer

The NDDM Project has successfully engaged with regional stakeholders through the workshops. The initial workshops were well attended with over 80 people present across the region. Additionally, an idea that was supported in the workshops was to hold an annual Ningaloo Tourism Futures Forum where participants would develop different scenarios which would be run through the model and discussed. Public agencies and authorities like DEC, DPI and the Shires will have a method of engaging with regional stakeholders when undertaking consultation for future planning, and for assessment of planning strategies. The tourism industry will have a potential tool for discussing future plans with the agencies and authorities. Finally, all groups would have a method for considering social, economic and environmental impacts when undertaking tourism planning.

Data generated by the project has already been useful to stakeholders for various projects underway in the region. Data from the visitors' survey was used when the Exmouth Visitor Centre commissioned a marketing plan for Exmouth, and was also used by DPI when undertaking consultation for a master plan on one of the pastoral stations. There are also indications that the data will be of use for future consultations and assessments of the Ningaloo Regional Coastal Strategy. The NDDM project has been publicised a number of times in the region and in the state, including 7 articles in regional and state-wide print media, a 7:30 Report story, and interviews with regional ABC Radio and on RTR FM's environmental program. Additionally, three newsletters have been distributed to stakeholders and flyers have been widely distributed in the region. The NDDM Project has also been the subject of presentations at one academic conference and a number of academic forums.

Next stage

The next stage of the project is further data collection for the rest of 2008 and ongoing workshops, beginning with workshops in May in Carnarvon, Coral Bay and Exmouth. A finished prototype of the Destination Model is due to be completed in June 2009. The final year of the project will examine ways of making the model applicable to other tourism destinations and potentially to other regional locations, particularly in Western Australia where regional communities are facing multidimensional problems and difficult questions over resource allocation.

Acknowledgements:

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Socioeconomic impacts of sanctuary zone changes in Ningaloo Marine Park: a preliminary investigation of effects on visitation patterns and human usage

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Objectives of study

The study involved gathering baseline data to assess potential socioeconomic impacts from the expansion of sanctuary zones in Ningaloo Marine Park on visitors and residents in the Northern Gascoyne and to make a preliminary assessment of any short-term impacts.

Methodology

One hundred and thirty-five Shire of Exmouth residents were surveyed about their views on the sanctuary zones and the extent to which the changes might impact on their activities. The survey involved a mail-out procedure using a random sample of one in five resident adults in the Shire of Exmouth.

An additional survey was carried out with 358 wilderness campers along the Ningaloo coast (ten months after legislation enforcing the sanctuary zones had been introduced). In addition to surveying wilderness campers and Exmouth residents, a range of data from two 2002 visitor surveys of wilderness campers were re-analysed and reconstituted as baseline data over a longer time period. Finally, a range of visitor data—including vehicle counts to the National Park, camping revenue, Visitor Centre door entry counts and aerial surveys of pastoral station camps—was collated and analysed in order to detect changes to visitation levels.

Key findings

From statistics provided by Tourism Research Australia for 2004 to 2005, it is estimated that 90,000 visitors converge on the Shire of Exmouth per annum, although this volume fluctuates. Approximately 30,000 visitors participate in recreational fishing. While the value of recreational fishing to regional tourism is a difficult matter to determine, it is clear that certain visitor markets, such as intrastate visitors, place a high value on recreational fishing as core to their visitor experience. However, a key finding of the project is that visitor experience is related to a general 'wilderness experience' in which recreational fishing is one of a constellation of activities that contribute to enjoyment of their holiday. The value placed on recreational fishing cannot be readily disentangled from other activities such as camping, swimming, enjoying nature and viewing wildlife that collectively forms the 'Ningaloo experience'. What this probably means is that fishing visitors have some resilience to changes in fishing regulations. However, it would be naïve not to think that at some point, changes may be of such a degree that some visitors decide to forego the Northern Gascoyne as their preferred holiday destination. Understanding visitors' level of satisfaction with the changes to the sanctuary zones and their intention to revisit the region was therefore a key objective in the surveys that were carried out for the project.

The wilderness camping survey indicates that, in the case of a core group of long-term fishing visitors at least, the sanctuary zone changes may have resulted in some modification of boat fishing activities and some localised displacement in terms of camping location. However, with the possible exception of a temporary downturn in wilderness camping in the Ningaloo station area during 2005 (the cause of which could not be determined), there appears to have been no sustained downturn in camping numbers along the Ningaloo coast, with levels having returned to normal in the early half of 2006. These are admittedly very short-term findings, and it is important that, before any firm conclusion regarding impacts from sanctuary zone extensions can be made, follow-up surveys are carried out in the future. The results of the survey also indicate that wilderness campers feel inconvenienced by the changes (with 80.1% of Ningaloo campers, for example, claiming to have been impacted by the changes), but not to the point that they do not wish to return to the region in the future, with 99% of campers indicating that they would visit the area again in the future. In fact, visitor satisfaction among campers for the Ningaloo Coast was extremely high (98.2% for Ningaloo campers and 94.8% for Warroora campers).

A theory referred to as the 'threshold of tolerability' is proposed which states that the more destination conditions change in ways which are contrary to visitor expectations, the more visitors will seek out alternative destinations (first locally, second regionally) or, alternatively, refrain from the activity altogether. In the case of Ningaloo, wilderness campers seem to have undergone the first stage of local redistribution but not the second of regional dislocation, indicating that the magnitude of the sanctuary zone changes are, for the time being at least, within their threshold of tolerability. This is partly attributed to the wide range of activities that wilderness campers engage in as part of the

'Ningaloo experience', even though recreational fishing is for many a key component of their visit to the Marine Park.

The survey of residents of the Shire of Exmouth found that over half of respondents (54.5%) were generally unhappy with the sanctuary zone changes and 57.6% felt that the activities of themselves or household members would be (or had been) affected, with some being forced to shift their boat fishing and cray diving activities. While it is possible that there was a response bias towards residents who had been mostly affected by the sanctuary zone extension, it is interesting to observe that these residents continued to visit the Marine Park in large numbers for a variety of activities, and from this perspective the sanctuary zone impacts had, at the time, been minimal in terms of rate of visitation by those mostly affected by the changes. The resident survey indicates that, amongst those dissatisfied with the changes, the opposition is directed particularly to the perceived process by which the sanctuary zone management plan was devised and implemented, and not so much to the principle of sanctuary zone protection itself. It is noted that external regulation is intricately related to satisfaction, with freedom and unhindered interaction with the natural environment being core to the 'Ningaloo wilderness experience' for both local residents and wilderness campers, and these principles being inherently in conflict with direct management techniques such as sanctuary zone exclusions. It is suggested that such feelings are less derived from anti-environmental attitudes but more from an attitude (one might say an 'ethos') of rugged individualism in regional areas such as the Northern Gascoyne. The degree to which this mindset adapts to incremental regulatory controls such as those relating to recreational fishing is a key issue for protected area managers, and one of the reasons why visitors and community responses to sanctuary zone regulation need to be closely monitored.

Future actions

Continued monitoring is important to understand long-term changes to visitor activity that may result from planning and management decisions concerning the Ningaloo coast. The impact assessment uncovered significant inadequacies in the level of understanding of visitor patterns in the Northern Gascoyne and the ability of agencies to monitor tourism activity and its social and economic impacts. It is recommended that the following matters be given strong attention by management authorities:

- recognition of the importance of robust research and evaluation in future management policies
- promotion of stronger interagency collaboration
- establishment of closer community partnerships in planning and management
- implementation of compulsory and systematic data collection and reporting procedures
- provision of a central data collection and access point.

Such measures are seen to be the key for understanding not only impacts from management decisions such as sanctuary zones, but also other local and external factors that affect visitation to the region.

The project team also suggests the following improvements be made to existing data gathering activities by agencies in the region:

- Aerial surveys should be conducted more regularly.
- Metro-count recordings in Cape Range National Park should be supplemented by random surveys of visitors by entry gate staff.
- Camping receipts need to be collected from both the National Park and the pastoral stations. An electronic method of storing receipt data is required.
- Visitor Centre bookings data need to be systematically collected and stored.
- Recreational fishing surveys by the Department of Fisheries need to report on fisher numbers and origins, not just fishing effort.
- Tourism satellite accounts need to be produced for the region.
- Visitor surveys of different market segments (such as those staying in commercial caravan parks and hotels/motels) need to be carried out.
- Residential surveys need to be conducted periodically.
- Comparison data for Shark Bay should be collected to distinguish local effects from regional effects.

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Estimation and integration of socioeconomic values of human use in Ningaloo in the management strategy evaluation model structure

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Project Description

The overarching objective of this project is to estimate the economic values associated with recreational fishing and marine recreation in the Ningaloo marine park. The methodology is based on estimating the consumer surplus values associated with recreational site/activity choices within the park (and substitute sites outside of the park). The measurement of the economic value of recreation is made difficult by the fact that the activity itself is often not directly purchased through markets. The values of conventional, market based economic activities are determined by the economic surpluses: estimates of profits on the production side, and estimates of the differences between the price paid for the good and the value to the consumer on the consumer side. Although there are some indirect measures of the economic activity associated with recreational non-market goods, such as expenditure incurred, these do not reflect the economic value to those undertaking the recreational activity (in fact, they are the costs, not the benefits). For example, transport, food and accommodation costs incurred by visitors fuel economic activity in the regional economy but the real gain to visitors is the economic surplus (or non-market benefits) they derive from their fishing or recreational activities, over and above their expenses. Identifying the economic value of non-market recreational activity requires specific approaches that allow surplus values to be identified, and here we applying Random Utility Models (RUM) based on site choice data. This project applies such models to recreational fishing and non-fishing recreational activities in Ningaloo, using secondary data for WA wide fishing activity, and a project-specific survey for recreational and fishing activity within Ningaloo.

A second component of the project is to incorporate "economic agents" into an agent based management strategy evaluation model, based on the estimated individual behavioral decisions. These can be used as the basis for simulated economic agents within a larger simulation model of the Ningaloo ecosystem. These agents are then free to interact with the environment and make choices about activity levels, leading to feedback responses from the environment to behavior, and then through ecological modeling back onto the environment. Because the models will be based on the theoretical decision framework, they will allow surplus value measures to be derived from changing management conditions in the park.

Recreational fishing RUMs at the state level

Quantifying recreational use values associated with "fishing experience, stock of fish, and site choices" in WA is limited and the methodologies require a revisit. Therefore, an initial objective has been to develop an empirical model of recreational fishing that can be used to analyse angler attributes and demand for fish and fishing sites. A RUM of demand for recreational fishing is used to measure the socio-economic benefits of this activity. These models allow the researcher to investigate a wide range of site substitution possibilities and, consequently, provide a procedure for estimating the economic value due to changes in site choices to assist fisheries management options. A state-wide model of site choice and economic value for recreational fishers has been developed and is being used to simulate the impact of changes in site quality, with a within-Ningaloo model under development.

The National Survey of Recreational Fishing (2000/2001) data is used to value recreational fishing at the state level. Four broad biological regions in Western Australia are covered in the study – the West Coast, Gascoyne, South Coast and Pilbara/Kimberley, disaggregated into 48 'sites'. Unlike previous studies based on this data, Ningaloo sites [1] are treated as a unique destination.

Site choice will depend in part on expected catch rates, and these need to be identified for both selected and non-selected sites. The expected catch is estimated with a count data model, and represents the catch as a function of annual stock and angler and site characteristics. Stock of the fish type [2] and the fishing method (target and using bait) are found to be critical in explaining catch. Age, whether retired and employment status are the three individual-specific

1 Ningaloo sites refers to four sites: Carnarvon, Quobba, Coral Bay and Exmouth in the Gascoyne region

2 As there are more than 300 fish species been caught, we classify them into five manageable fish types, namely Prize fish, Reef fish, Key Sports fish, Table Fish and Butter Fish, based on the department of Fisheries bag and size limit.

Table 1.

Per Trip Value for Change in the Catch Rate of Each Fish Type

		Value of Fish ($) for	
Variable	Sample mean catch	Additional one fish	100% increase[3]
Prize Fish	1.28	15.94	31.41
Reef Fish	1.47	1.48	22.13
Key Sport Fish	1.39	9.40	21.79
Table Fish	1.97	4.65	14.88
Butter Fish	8.86	2.28	20.20

Table 2.

Annual Aggregated Welfare Losses[4] associated with closure of the Ningaloo Fishing Sites

Sites in Ningaloo	**Aggregate across population ($ million)**
Carnarvon	-2.27
Quobba	-3.30
Coral Bay	-1.12
Exmouth	-1.72
Closing all four sites	-9.08

characteristics that enter the models and explain the expected catch. This model is then used to generate expected catch rates per individual/per site. The RUM estimation of site choice demonstrates that travel cost and expected catch rates by fish type are significant in explaining site choices. The catch rates of the fish types give the measure of the quality of the fishing sites.

Current findings and their implications for management

Based on this model, some simulations of management policy changes have been conducted. These are intended as indicative of the form of analysis possible, and not actual policy proposals. We stimulate: 1) site quality change by changing the catch rate marginally across all sites; 2) site-specific quality changes and closures. Table 1 reports the estimated value associated with an increase in expected catch per trip of one fish, and the value of a 100% increase in catch rate, by fish type. These increases are assumed to occur throughout all sites.

Table 2 shows the estimated loss in value, associated with complete closure of specific sites to fishing.

Valuing recreational activity within Ningaloo.

Secondary data is not sufficiently detailed to allow the identification of policy relevant site choice behaviour within the Ningaloo region. Therefore, the project has collected data specifically on recreational activities in the Ningaloo region. The surveys were distributed across the region from Red Buff to Gales Bay. The survey instrument contains three parts:

1. Maps (Recreational and Fishing Sites)
2. A Trip form
3. Log Book, including
    - Information on “how to fill out your log-book”
    - Log books for fishing trips (blue) and for recreational trips (yellow)

The survey gathers significant detail, including, *ex ante* and *ex post* information about all aspects of recreation undertaken. The log books allowed up to 7 trip events per respondent to be collected.

In total 90 usable log books have been returned to date yielding 314 trips for analysis. Coral Bay and Turquoise Bay are the most visited sites in this sample. Coral Bay and Exmouth are the most common places people stay. On average, cost of travel followed by isolation are the most important reasons ranked for choosing specific sites to visit. Diving, sight seeing and bush walk are the recreational activities carried out by the participants in the region. Figure 1 illustrate the mean rank of recreational activities undertaken by participant in the sites, measured on a scale of 1 to 5.

The survey is currently ongoing, and will be the basis for estimating RUM models for both fishing and recreational site choice, to provide estimates associated with changes in access conditions or quality of sites within the park.

Agent-based modelling

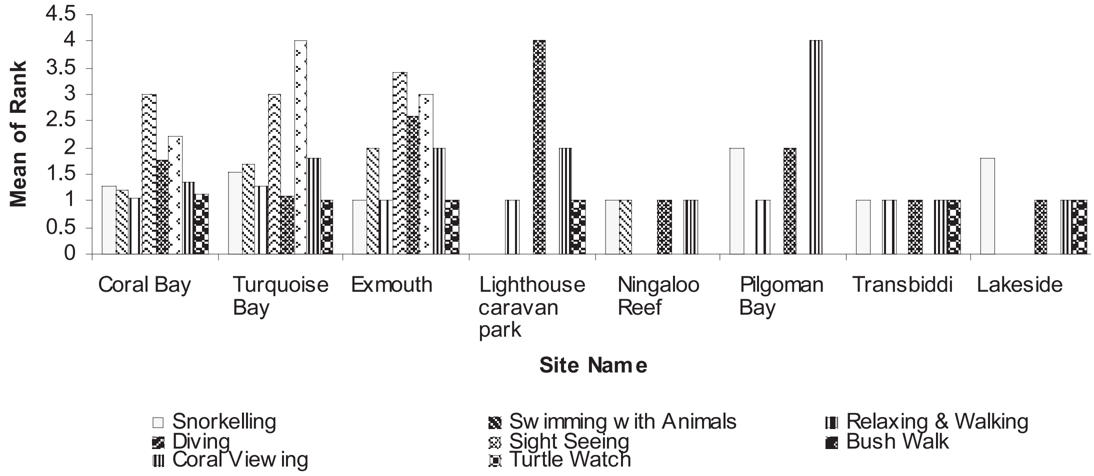
The second component of the project involves the construction of an agent-based model (ABM), structured using

3 It may seem counterintuitive that the impact of a 100% increase leads to such significantly greater increases in value compared to the addition of a single fish, when, on average, the increase in fish may look equivalent (e.g. an increase of 1 and 1.28 for prize fish). The effect is caused by the variation in expected catch rates across the fishers, and that proportional changes in catch rates cause changes in site choice, while uniform, unit changes do not. As a result, the greater absolute increase in the high catch rates leads to a double impact: an increase in value from the additional fish, and a shift in site choice towards those sites. This emphasises the importance of evaluating the average of the individual values, as opposed to the value associated with an ‘average’ individual.

4 The aggregated welfare losses of fish sites for the population are based on a total of 10million fishing days annually in WA (Baharthah and Sumner, 1999) and on 53.5% of fishing days as shore-fishing days (calculated based on NSRF data).

Figure 1.

Mean Ranks of Recreational Activities



the RUM model results, as a contribution to the Ningaloo Management Strategy Evaluation (Ningaloo MSE) or InVitro model that ties together different biophysical, socio-economic and management models from across the Cluster. The agent-based model comprises a population of agents who make site choices using data inputs from the other models (e.g. on fish stocks and other indicators of site quality). The outputs from this model include the spatial distribution of recreational and fishing activities, fish extraction rates on the different sites as well as economic surplus measures indicating the benefits visitors obtain (over and above their spending in the region) under the prevailing management regimes for the Marine Park.

The agent-based model has the following three components:

1) A trip demand model predicting the number of visitors to the Ningaloo region and their demographics. This model utilizes estimation results from a state-wide fishing site choice model estimated by the project (see above) and visitor count data gathered by Projects 3 and 2 of the Ningaloo Cluster.

2) A site choice model structured using parameters from the RUM models estimated using Ningaloo recreation data collected by this project and the state-wide fishing site model.

3) A resource utilization/extraction model that serves as the interface between the recreational site choice models and other components of the Ningaloo MSE model.

By integrating recreational site choice results into the simulation of biophysical processes and by adding economic surplus measures for recreation into the socio-economic performance criteria, the Ningaloo MSE model will enable researchers and resource managers to evaluate and compare alternative management regimes in a more complete way than would be possible if only regional economic effects of recreation are taken into account.

Next Steps

The project is currently undertaking a rolling survey administered through a resident in Ningaloo to augment the survey responses obtained through previous surveys, some of which were done in conjunction with Project 3. Data collection will be completed by December and RUM model for Ningaloo estimated. The recreation RUM model and the state-wide fishing site choice model discussed above will be used to parameterize the agent-based model. A prototype agent-based model is currently under development. The final phase of the project is to use the model for the simulation of the biophysical and economic effects of management changes including: fish stocks; bag limit changes; site and reef qualities; site availability or access restrictions; and site use charges or fees.

Key words: Non-market valuation, recreational demand, Random Utility Models, welfare measures

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The policy relevance of choice modelling: an application to the Ningaloo and proposed South-West Capes Marine Parks

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Abstract

This study applies the economic Choice Modelling (CM) technique to the Ningaloo Marine Park and proposed South-West Capes Marine Park in Western Australia. The study aims to investigate the suitability of CM as tool for valuing marine parks and provide estimates of specific non-use values (e.g. conservation values) in each park that can be considered in future marine policy and planning. Potential management processes and conservation outcomes are also considered within the study to obtain information on general public and expert scientist preferences for input in to future management decisions. The public and expert preferences will be compared to determine if they diverge, and if information and publicity effects play a role in preference formation regarding management of the marine parks.

Project description

The Ningaloo Marine Park is undoubtedly an important public asset to many West Australians. In symmetry with other marine parks along our coastline, Ningaloo is important for many recreational and commercial endeavours, both of which make an important economic contribution to the State. Equally as important, if not more so, are the conservation and existence values of the marine park. Ningaloo is renowned for its biodiversity that is enjoyed by the many users of the marine park, but may also be considered valuable by others for their pure existence.

Values for environmental public goods, such as Ningaloo, that are held by people who may have no intention of physically using the good, but still consider it to be important, are referred to as non-use values (Bateman et al. 2002). Non-use values encompass the existence and conservation values, and values such as altruism and bequest, where you may value the knowledge that other people can use the good or that it is being preserved for future generations. These values have been under-represented for marine parks and coral reef systems in general, despite their obvious importance – conservation is usually a priority goal in marine parks suggesting non-use values should be a vital ingredient for decision making (Spurgeon 2001). Choice Modelling (CM) is an economic technique capable of capturing and isolating these values, essentially inferring their non-market value and expressing it in 'dollar value' (Bateman et al. 2002). The technique is becoming increasingly popular in policy use as it provides information on the non-market aspects of a public good that can then be directly compared to other economic costs and benefits associated with the good and aid decision making processes.

This project will estimate the value of specific ecological attributes in the Ningaloo Marine Park and also the proposed South-West Capes Marine Park, located in the south-west of WA (hereafter referred to as the Capes), through the use of CM. CM employs the use of a questionnaire that applies a hypothetical market scenario to the good in question, allowing respondents to state their preferences for varying policy or management scenarios. The main focus of the questionnaire is a series of questions referred to as choice sets. The choice sets contain a list of the attributes of interest regarding the good, and a series of hypothetical options that vary the levels of the attributes offered, representing possible policy or management variations (Figure 1). In each choice set the attributes remain the same, but the levels of the attributes and the management options are different. The respondent must choose their preferred option in each choice set, one of which is a status quo to represent the current situation. One of the attributes is termed a payment vehicle, and it provides a cost associated with each of the varied options. The payment vehicle provides the ability to estimate the value of each of the attributes through statistical analysis (Louviere et al. 2000).

This project attempts to provide information on preferences towards potential management options for the two marine parks, and generate value estimates of the attributes and potential management combinations. Three specific areas of investigation include: isolating the important non-use values; identifying impacts of alternative management processes on values, and the potential divergence of public and expert opinion – all of which are important in generating information for marine park management.

Typically CM studies are concerned with respondents' preferences for management outcomes. However, it is possible that preferences may hinge on the process through which the outcome is achieved (Johnston and Duke 2007). For example,

1 PhD research UWA, supported by UWA UPA with additional support from WAMSI

Figure 1.

An example of a choice set similar to those being used in the Ningaloo Questionnaire. The list of attributes in the first column and the hypothetical management options in subsequent columns that vary according to the 'level' of the management outcome offered for each attribute.*

*Note: This choice set is intended as an example only and does not include the management process levels that are discussed below.

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

Environmental Feature	**Option 1** *Status quo*	**Option 2**	**Option 3**	**Option 4**
Conservation of coral reef	0% more coral	10% more coral	5% more coral	5% more coral
Conservation of target fish stocks	0% more fish	5% more fish	10% more fish	10% more fish
Conservation of Turtle populations	0% more turtles	5% more turtles	5% more turtles	10% more turtles
Conservation of Whale Shark population	0% more whale sharks	0% more whale sharks	2% more whale sharks	5% more whale sharks
Cost to you per year in environmental taxes	$0	$40	$20	$80
Please tick **One** box for the option you choose	☐	☐	☐	☐

a desired outcome may be the improved conservation of fish stocks in the marine park, but preferences for this may depend on whether the conservation target is achieved by different processes such as increasing the percentage of sanctuary zones or by decreasing the possession limit of fish for recreational fishers in the marine park. This study will include both an outcome and process component for each ecological attribute under consideration in an attempt to provide more relevant information for decision makers.

In terms of considering public and expert opinions, questions often arise as to whose opinion is important and are they different (Kontoleon et al. 2001)? The probable answer to the first question is that both opinions are important when considering a public good, however this study aims to provide some grounding on the second question as to whether the opinions diverge. The CM survey will include samples of the general Perth Metropolitan public[2] and expert marine scientists. This will allow a comparison of preference formations between the two populations. Within the public samples information effects will also be examined to determine if more information leads to a convergence of preferences similar to that of the experts. Publicity factors will also be considered with the well known and highly publicised Ningaloo Marine Park in contrast with the recently proposed Capes.

It is envisaged that this project will be a useful application for future management decisions regarding Ningaloo and the Capes, and potentially other WA marine parks. The CM tool is able to test the ground and determine people's reactions to changes in management and policy before it is decided whether the change should be put in to place. The consideration of management processes and outcomes will provide detailed information on public preferences, and the public/expert comparison of preferences will provide an insight as to whether it is vital to consult the public on these management decisions. Furthermore, it will provide a valuation of specific non-use values in each marine park in an attempt to add these data to marine park literature.

Through these investigations the project will also provide input to the debate on the general policy relevance of CM – the technique is often questioned given its hypothetical nature, but is the best available option in cases where non-use values are of high importance. This study will shed some light on whether public consultation through CM is essential based on the public/expert comparison, and whether the inclusion of management processes improves CM relevance.

In summary, the main aims of the project are to:

- Investigate the suitability of CM as a tool for valuing marine parks and coral reefs by applying the technique to the Ningaloo and Capes marine parks,
- Estimate the non-market value of the Ningaloo and Capes marine parks through the use of CM, with a specific interest in non-use values,
- Investigate the potential for divergence of values for an environmental good between public and expert groups, with specific reference to non-use values,
- Investigate the relevance of including management processes as well as outcomes in the CM survey,
- Provide usable information for marine policy and planning on non-use values and management preferences,
- Contribute towards determining the policy relevance of CM via these investigations.

2 Local public samples of the marine parks are not considered at this stage as the majority of these samples would be users of the marine parks, and as such it would be difficult to isolate non-use values.

Current findings and their implications for management

Preparatory work has been undertaken to determine relevant ecological attributes (as these pertain to non-use values) and management processes to consider in the CM survey. The majority of the ecological attributes in each marine park are Key Performance Indicators (KPI's, as represented in each parks Management Plan). These attributes are considered to be of particular importance for management and monitoring reasons within the parks. Potential management processes have been established both from the literature and liaison with marine managers that are aimed at generating information on management preferences that will be highly beneficial upon consideration of future management directions in the two marine parks.

Knowledge transfer

The marine related objectives of the research should ensure the results of the project are particularly relevant for marine policy makers. They will provide firstly a context for valuing non-use values of other marine parks, and secondly an overview of the non-use values for the Ningaloo and Capes Marine Parks. The CM approach will enable policy makers to envisage public preferences and reaction towards potential management changes in these parks, and create an awareness of any existing differences in public and expert opinion regarding the parks. The findings of the project will be presented at a WAMSI event and the Australian Agricultural and Resource Economics Society Conference in 2009, among others.

Next stage

The survey will be administered during mid-2008, after which the data will be analysed intensively with particular focus on isolating non-use values, the comparisons between public and expert samples, and the effects of management processes and outcomes. A future avenue for research could be to target a localized public sample for each marine park for comparison against the expert and Metropolitan public samples.

Acknowledgements

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Historical baselines of finfish in the Ningaloo Marine Park: a concise report

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Abstract

This paper summarises the main findings of an historical study to determine baseline finfish stocks in the Ningaloo Marine Park utilising 15 oral histories and archival research. It identifies some of the findings which were consistent across data sources, including trends in fish stocks and major environmental impacts. Finally, it documents the difficulties faced by those interested in researching finfish baselines and highlights the importance of a multi-disciplinary approach.

Project description

The DEC acknowledges that current understandings of finfish stocks and their inter-temporal changes may be adversely affected by 'shifting baseline syndrome'. The concept of shifting baseline syndrome in the marine context was first articulated by Daniel Pauly who, in 1995, stated that, "each generation of fisheries scientists accepts, as a baseline, the stock size and species composition that occurred at the beginning of their careers, and uses this to evaluate changes,"[1] subsequently, he claimed the extent of change in marine environments over the medium and long term is constantly underestimated. The acknowledgment of shifting baseline syndrome increased the demand for historical baseline data of finfish stocks in the Ningaloo Marine Park.

Several recent studies have given weight to Pauly's concern about shifting baselines in fisheries, leading to an increase in recognition among ecologists and natural resource managers that historical perspectives of the natural environment can help illuminate the variety, scope, and causes of environmental change. The DEC's first management plan for the Ningaloo Marine Park cited the lack of information regarding the ecology of the Reef, and the population dynamics of organisms, as a critical deficiency. The plan outlined a number of future research projects designed to fill this knowledge gap and establish baseline data from which management practices could be evaluated.[2] However, as this initial plan gave no consideration to the construction of an environmental history of the Park, the baseline data that has been developed draws predominantly from the fish density survey conducted by A.L. and A.M. Ayling in 1987;[3] a 12 month creel survey of recreational boat-based and shore-based fishing in the Gascoyne bioregion conducted between April 1998 and March 1999;[4] and non-Ningaloo based finfish research.[5]

Baseline data from the 1980s and 1990s is insufficient to establish a reliable baseline for sustainable fisheries management. This fact is implicitly acknowledged in one of the DEC's 2005-2015 management plan key performance indicators, which calls for the "abundance and size composition of finfish species in sanctuary zones and conservation areas to be at natural levels."[6] The footnote accompanying this KPI defines the natural level as "the abundance that would occur in that area undisturbed and/or unexploited by human activities"[7] but is unquantified. Given the extensive human engagement with the Ningaloo marine environment prior to the mid 1980s, it would be naive to assume that the current baselines are representative of the 'natural' level. Acknowledging this deficiency, and the role that historical perspectives of the marine environment play in improving our understanding of the impact of human activities on an environment, the most recent management plan cited "research into the history of exploited marine animal populations" as a key research strategy.[8] It is in this context that the current research was undertaken.

1 D. Pauly, 'Anecdotes and the Shifting Baseline Syndrome in Fisheries', p. 430.

2 Specifically, the plan states that "There is an urgent need for baseline data on reef community structure and natural rates of change... CALM has commenced a research program in the fields of physical oceanography and marine biology, aimed at providing baseline data to aid future management." (CALM, *Ningaloo Marine Park Management Plan 1989-1999*, p. 34.)

3 A. Ayling, and A. Ayling, *Ningaloo Marine Park: preliminary fish density assessment and habitat survey*.

4 N. Sumner et al., *A 12 month survey of recreational fishing in the Gascoyne bioregion of Western Australia during 1998-99*.

5 An article titled 'N-W fish survey gets underway', written between 1974 and 1977 and contained in a scrapbook archive in the Exmouth tele-centre states that Captain Sheridan and Biologist Dr Keith Sainsbury were undertaking a fish survey aboard the vessel Courageous. No resulting report was located.

6 CALM, *Ningaloo Marine Park Management Plan 1989-1999*, p. 46.

7 CALM, *Ningaloo Marine Park Management Plan 1989-1999*, p. 46.

8 *CALM, Ningaloo Marine Park Management Plan 1989-1999*, p. 100.

Current findings and their implications for management

Drawing on sources ranging from newspaper articles, fishing guides to scientific studies and 15 oral history interviews, this study describes the changing nature of human engagement with the Ningaloo marine environment, and examines the perceptions of changes to stocks of individual fish species, and finfish generally. The research was conducted as part fulfilment of my History honours degree at the University of Western Australia and benefited greatly from the support of the DEC. In this abstract I provide a brief summary of my research into finfish baselines in the Ningaloo Marine Park, with a particular emphasis on the methodological challenges, summary results, and policy implications. It highlights the seriousness of shifting baseline syndrome and suggests some ways to mitigate it and should therefore be of great interests to scientists and policy developers in both the Ningaloo Marine Park and marine ecologies generally.

Building upon the oral history research of Paul Weaver[9] and Peter Mack[10] 15 oral history interviews with a total of 16 informants were conducted over a period of three months. Furthermore, more traditional document based research, including newspapers, magazines, field diaries, government and university publications, generations of fishing guides and state archives was undertaken. The key finding of the study is that, while there is a widespread perception of a decline in the density and average size of several fish is widespread and of extensive pressure placed on the finfish population by human actions, there are vast methodological limitations associated with the quantitative interpretation of the available source material which ultimately prohibit the creation of a robust historical baseline. I explore these issues in more detail below.

The research highlighted some common themes relating to Ningaloo Marine Park fish stocks. For example, the majority of informants believed that finfish stocks have declined in density and average size since the 1960s but that the maximum size of all fish has not changed. Further, there is a consensus that the larger Spangled and Red Emperor are more difficult to catch than they once were. Interestingly, there is a significant difference between the maximum sizes indicated by Fisheries and those recalled by informants for the Red Emperor, and an interesting anomaly in the length/weight relationship of the Spangled Emperor.[11]

Various human activities were identified that are likely to have placed significant pressures on fish stocks prior to their first scientific description. Consideration should be given to them when attempting to estimate “natural” baselines. These activities are listed and described in length in the full version of this report and in addition to traditional line fishing include strafing runs, fishing with explosives, and spear fishers. This type of data may be of use to scientists and policy makers because it is highly geographically specific and benefits from the insight of locals as to which specific species are most likely to be affected by certain activities. However, this study is unable to provide specific quantitative data regarding changes in the size or density of any of the finfish studied. Next I discuss the methodological limitations which preclude the unequivocal confirmation of the magnitude, or even direction, of changes to finfish stocks.

In large part, the lack of reliable quantitative findings is due to the uniqueness of the Ningaloo Marine Park. Unlike many coastal marine environments, there is no long-term marine based industry from which to source decades of quantitative data. Furthermore, due to the transient nature of the early workforce, intergenerational ecological knowledge is limited. Finally, the vast and rapid changes in this area are arguably greater than has been experienced in most other coastal marine environments. As such, where oral history informants have observed actions which one could reasonable assume to have adversely impacted the environment, it is difficult to find quantifiable data or other source material to confirm the impact of these pressures.

A significant limitation in this study has been the inability of most fishers to give length or weight descriptions of finfish species, and the lack of Ningaloo based source material relating to specific species of finfish. This limitation is magnified when one considers the impact of changes in technology, access, learned skill and ecological knowledge, and personal fishing practices. These changes affect fishing experiences gradually and subtlety, potentially distorting the memories and perceptions of fishers in an environment. Due to the confounding effects of these changes even general conclusions about the likely direction of impacts on finfish stocks are not as simple as they may first appear. For example, a fisher who claims that fish are as abundant as they were forty years ago may in fact simply be benefiting from her increased local knowledge and improved technique while operating in a severely depleted environment. On the other hand, a fisher who claims that fish stocks are severely depleted may simply have failed to adapt to natural changes in fish behaviour and location. This research argues that the cumulative effect of the aforementioned difficulties, along with the more standard methodological challenges associated with the effect of cultural ideology and psychology on memory (discussed in length in the full version of this report), and the influence of the interviewer, is such that they ultimately prohibit

9 P. Weaver, *An oral history of Ningaloo Reef: Transcripts*, Fremantle, Department of Conservation and Land Management, 1998.

10 P. Mack, *It was quite amazing really: stories from the Ningaloo Coast*.

11 For a detailed description of these and other findings, please contact the author.

the creation of a robust historical baseline of finfish in Ningaloo other than to say the environment has most likely been negatively affected by human interaction.

Knowledge transfer

The inability of this historical research to produce what scientists would consider 'usable data' is not unique, or even unexpected. Environmental histories fuse the environment with the human history of an area, and thus contend not only with changes to the environment but also with the impact of social, economic, and political changes on the human population and their engagements with, and ideas and perspectives of, nature. This understanding is then, most often, packaged in the form of a narrative, not the 'hard' quantitative data that scientists and many policy setters are more familiar with.[12] While methods are being developed to bridge the divide between available historical and desired quantitative data (such as Mackinson's use of the CLUPLEX, a model developed in the framework of a fuzzy logic expert system that handles both 'hard' and 'anecdotal' data.[13]), at present the products of historical endeavours are rarely practically utilised in the formulation or assessment of management practices: in part because qualitative, historical, local ecological knowledge does not lend itself well to mathematical representation and numerical modelling.[14] This research provides a timely reminder that neither scientific nor historical data can produce exhaustive data on the 'natural' level of the "abundance and size composition of finfish species in sanctuary zones."[15] Realising this, and incorporating both historical and scientific research, policy setters will be better armed to tackle the formidable and vitally important task of maintaining our unique natural environments.

This research has highlighted the challenges faced by policy setters when relying on scientific and historical finfish stock data. Failing the creation of substantial paleoecological data to gain robust scientific understanding of the finfish populations in the Ningaloo Marine Park, it would be prudent of fisheries management to assume that the anecdotal historical evidence collected in this research is reflective of the true state of the marine environment; i.e., it has been subject to extreme pressure and current baselines fall short of the 'natural' level.

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12 For a thorough discussion of the place and perils of narrative in environmental history see Cronon, W., 'A Place for Stories: Nature, History, and Narrative', 1364-1376.

13 Mackinson, 'Integrating Local and Scientific Knowledge: An example in Fisheries Science, p. 533-535.

14 For examples see Mackinson, 'Integrating Local and Scientific Knowledge: An example in Fisheries Science' and also Neis et al., 'Fisheries assessment: what can be learned from interviewing resource users?', p 1950-1955.

15 CALM, *Ningaloo Marine Park Management Plan 1989-1999*, p. 46.

Knowledge transfer and management support tools

Science and management: building a framework for knowledge transfer

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It is imperative that science informs natural resource management decisions and practices. This concept is certainly integral to recent research initiatives such as the Western Australian Institute of Marine Science (WAMSI) which holds as its theme "better science means better decisions". This theme is supported by government as it has invested significantly in research programs to provide sound science to underpin management and decision making capacity. The Ningaloo Research Program (NRP) is one such example of government investment in science to inform and substantiate management initiatives. The success of the NRP will rely on the effective transfer of knowledge between scientists and resource managers so that research outcomes are acknowledged and incorporated into management actions.

However, the transfer of knowledge from science to management is not a seamless process, and can often be problematic. The issues that can inhibit this process have been reviewed by various studies (e.g. Briggs 2006; Woodley 2006; Roux et al 2006) that have highlighted, for example, differences in culture and priorities, different understanding of questions and limited effective communication between scientists and managers. We do not intend to add to that body of literature by analysing such problems and posing theoretical models for knowledge transfer. Rather, we hope to focus on the interaction between science and management and how we might build a better framework to transfer the improved scientific understanding that is currently being developed through the NRP into better management of the Ningaloo Marine Park.

The Ningaloo Research Program

The NRP came about due to a specific identified need by the WA government in 2004 for a stronger scientific underpinning to support the management of the Ningaloo marine reserves. This need was triggered by public concern over a proposed tourism development at Maud's Landing near Coral Bay in the Ningaloo Marine Park and to controversy surrounding the rezoning of the NMP in the same year. The WA Government concluded that the current scientific understanding of the Ningaloo Reef area was inadequate to ensure the sustainability of further tourism developments and to effectively implement management strategies outlined in the Ningaloo Marine Park management plan. At that time the State government committed $5M to a program of research that would underpin the conservation and management of the Ningaloo Marine Park.

A research program was duly developed in consultation with the research community and resource managers that would address priority research needs identified in the Ningaloo Marine Park management plan. The funding was administered through WAMSI's Node 3. At the same time, the CSIRO Wealth from Oceans National Research Flagship program initiated a Ningaloo Collaboration Cluster to complement the research planned through Node 3 of WAMSI. These research programs are collectively known as the Ningaloo Research Program (NRP) and include additional core and industry funded research conducted through AIMS. In addition to the government funding provided through WAMSI and CSIRO, the NRP has attracted significant collaboration and co-investment from universities and other research bodies, and is currently valued at approximately $30M. The four-year research program is investigating a broad variety of physical, ecological and social themes relating to the Ningaloo Marine Park. There is an expectation that outcomes from the NRP will directly assist management of the marine reserve. Thus the link between science and management is critical to the success of the NRP.

Knowledge Transfer and some limitations

We use the term knowledge transfer to mean the incorporation of scientific understanding and information into management practices at the policy, planning and operational levels. Natural resource management typically relies on an adaptive management framework to ensure that management utilises the best information currently available, while also adapting to new knowledge as it becomes available. This model thus provides the capacity to evaluate and refine the effectiveness of management strategies (Figure 1). There is a clear requirement in this process for the inclusion of science into management, and several points in the model where knowledge transfer or information flow is critical.

Knowledge transfer often refers to the later stages in the adaptive management cycle, when research outcomes are used to generate recommendations for changes to management. However, communication and information transfer are necessary at each stage for the process to work effectively. For example, close communication between scientists and managers during the assessment phase would ensure that both have the same perception and understanding of the issue at hand. Managers then must provide direction to scientists by identifying the key management questions. Scientists will base their research upon their understanding of

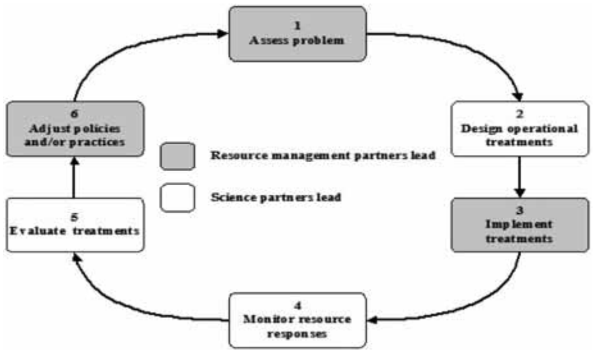

Figure 1.

Diagram of Adaptive management framework used in natural resource management, noting the role of resource managers and scientists.

the issue and the key questions and will then communicate their findings in the evaluation phase, including making realistic recommendations for management.

Typically when a contentious issue arises, knowledge transfer can be rapid, as the political pressure to identify a solution may be intense. Research may be commissioned or scientific expertise sought and the relevant information fed directly into management strategies and outcomes. The process is enhanced by the level of motivation on both sides and by the clear lines of communication that typically operate around contentious issues.

An example of the ease of knowledge transfer in a contentious climate would be the interaction between the Western Rock Lobster Fishery (WRLF) and the Australian sea lion *Neophoca cinerea* (Campbell et al. submitted), which is listed as 'vulnerable' under the Commonwealth *EPBC Act 1999* and as 'specially protected' under the Western Australian *Wildlife Conservation Act 1950*. The issue of sea lion mortality in lobster pots was raised for the WRLF and research duly undertaken to assess the significance of the threat and development of a sea lion excluding device (SLED). Regular communication occurred between industry, fisheries, wildlife managers and researchers to identify the problem, investigate potential solutions and then put those solutions into practice. The outcome has been changes to the WRLF including mandatory use of SLED on fishing gear within high interaction zones. In this example knowledge transfer was rapid and effective because there was an important identified issue at stake and there was consistent collaboration and regular communication between all parties including scientists and resource managers throughout the process.

As noted by other authors, the culture of science differs markedly to that of resource management. The focus in science is on the production of results that may be presented to the scientific community through a peer-review process. Thus, there is the expectation that collaborators and the audience will share an understanding of the issue, the science methodology and, in many cases, a particular technical language. There is often limited communication with the general public, and typically little requirement to adapt the language or the messages to suit a broader audience that lacks those technical skills and expertise. Similarly, there is often limited effort made by scientists to communicate results to resource managers in a format and in non-technical language that can be understood and more broadly interpreted.

Alternatively the culture of resource management is typically focussed on practical outcomes, often in a political context. There may be a need to provide answers and make decisions in a very short timeframe. While the aim is to make the most informed decisions, including sound scientific input, managers will make decisions on the best available information that provides them with a clear and defensible way forward. Decisions are typically open to public scrutiny and must be presented and often explained publicly to a broad audience with varying levels of scientific and technical understanding of the issue.

As such, science is an important tool for managers to harness and use in their decision making. However, many managers are aware of the limitations of science in relation to policy and decision making. Among these limitations, for example, is that scientific results may often be inconclusive or ambiguous with regard to the questions posed by managers. Further, scientific results can often by highly qualified, and there may be a lack of consensus among scientists regarding particular findings. For these reasons, along with the often disparate time frames and priorities between science and management, science and research outcomes are usually only one part of the decision making process.

In general, the key priorities of resource managers are conservation and sustainable use. They must make publicly-accountable decisions in a timely manner using the best available information. Finally, they must often take account of social and economic concerns in addition to science outcomes. Thus, while their actions might not reflect recommendations that would lead to the highest level of conservation based on science, they might in fact relate to an acceptable level of conservation that will also meet related social needs or political imperatives. Basically, resource management can be seen as a balancing act with scientific information representing only one, albeit significant, aspect of the decision-making process.

Three relatively broad issues may be considered to form the basis for effective knowledge transfer. The first of these, as outlined above is that managers must have, at the very least, a general understanding of culture and limits of science.

Secondly, scientists must have an understanding of management processes, including the constraints imposed on managers. Strategies that are typically used in natural resource management to ensure sustainable resource use include administration (e.g. policy and planning), education, enforcement, public participation, management intervention, research and monitoring (including evaluation and reporting). An awareness and understanding of these, and how they are used in management, is important in order to frame research findings into recommendations for management that will lead to improvements in biodiversity conservation.

Finally, there needs to be an 'interface' that brings the science and the management together, where information exchange may occur and be translated into the relevant language and format appropriate to science or to management/policy. This requires means for a dialogue between managers and scientists where thoughts and ideas may be shared and progress made together. Open communication throughout the process is critical and may rely on 'key' positions occupied by people with experience in both the science and policy or management environments.

Knowledge transfer through the NRP

The Department of Environment and Conservation (DEC) is the agency responsible for the management of the Ningaloo Marine Park, and thus the agency that is both directing and will be the primary user of information gained through the NRP. However, the research being undertaken in this program is being don so predominately by external agencies and organisations (e.g. CSIRO, AIMS, Universities). In addition, the NRP came about as a political initiative to improve the scientific underpinning for the management of the Ningaloo Marine Park, it does not involve solely contentious issues. Rather, the research program is designed to provide background and supporting information to assess the management strategies currently in place and establish long term monitoring strategies to evaluate and adapt management as needed over time.

The DEC recognises that knowledge transfer will be one of the critical steps in capturing the value from the NRP and thus ensuring its success. To enhance the capacity for knowledge transfer, it is our role to build on the interface between science and management in this process and ensure communication is consistent and ongoing. There are a number of initiatives that have been completed or are underway to achieve this including:

- The development of the NRP research plan directly from the research priorities identified in the Ningaloo Marine Park management plan and in consultation with the research community;
- The identification of discrete management questions by the DEC that are associated with each research project and discussion of these questions with the relevant project leaders;
- The integration of research effort between the various agencies and institutions working on the Ningaloo Marine Park through the Ningaloo Research Coordinating Committee;
- The development of a detailed NRP communication plan that identifies, for example, communication goals, key objectives and messages, target audiences and activities in which all participants may engage;
- The development of a NRP data management plan that highlights the importance of producing clear metadata and identifies storage sites for metadata and data (where applicable), so that information will be accessible to all;
- An annual Ningaloo Research Symposium for scientists and managers; and
- A progress report to showcase the projects currently underway and provide updates on recent findings, their potential implications for management and future directions.

Future directions

We anticipate continuing to develop sound pathways for knowledge transfer between researchers and managers involved in the NRP. To assist this process, we will work with principle investigators to further review the management questions identified for individual projects, to ensure a mutual understanding of management needs, why such questions are asked and in what way the answers may reflect on future management strategies and directions. We will continue to encourage the timely publication of results, communication of results to the broader public wherever possible and compliance with data management protocols.

Over the next 12 months we will be developing a framework that highlights the management questions that are under investigation, and potential management outcomes/strategies that may address them. This project will focus on assisting the scientists to develop their understanding of management options and instruments thus allowing them to formulate management recommendations for final reports and scientific papers. Finally, at the end of the NRP a report will be produced that will pull together the various streams of research including the science and the outcomes, into the context of improved management for the Ningaloo Marine Park.

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Modelling for management: news from Ningaloo

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Abstract

Juggling the many demands on coastal marine ecosystems is a particularly uncertain and challenging task. These areas see the greatest ranges of human activities and are simultaneously the location of many ecological processes – such as production, nutrient cycling and critical life history phases. This means that the areas with the greatest role in supporting the overall system can be those most directly under pressure. Robust management is required to prevent untoward impacts degrading the value and function of these systems. Such management can not simply deal with direct impacts, but must also give consideration to indirect effects and trade-offs between components of the systems and objectives of different user groups. Models of many forms are very helpful in teasing out these issues and allowing for an informed decision making process. We will present a brief outline of how the many different modelling efforts underway on Ningaloo fit together as an information jigsaw; and how that is being built on to form a whole of ecosystem model, which is being constructed using the InVitro modelling framework. To illustrate the potential of the approach, a hypothetical example will be posed - drawing on existing ecological components (e.g. whale sharks, reefs and their associated fauna) and prototype human components (e.g. tourists or contaminant plumes).

Introduction

Information Jigsaw

Modelling is a very useful way if integrating information on a system, increasing the understanding of alternative driving mechanisms, identifying critical gaps in knowledge and 'road testing' ideas before actually implementing them in reality. Across the collective body of work formed by the research in WAMSI and the CSIRO cluster a range of models are being developed for the Ningaloo region.

For anyone outside the immediate circle of modellers the collection of Ningaloo models can seem confusing and potentially redundant. The best means of correcting this misconception is to think of the different components of the Ningaloo system as pieces in an information jigsaw with the models pieced together from one or more of these puzzle pieces (Figure 1). Some of these models are very focused (e.g. the hydrodynamic modelling in Node 3-5) while others are more expansive (e.g. the destination and load modelling being done in Cluster project 3). These modelling efforts should all be thought of as complementary, highlighting different aspects of the systems and the interactions within it. The most inclusive model of all is the Management Strategy Evaluation model (Cluster project 5.3), which brings together all of the system components and their interactions. This model will allow for simulation testing of alternative future scenarios and management strategies and will highlight tradeoffs between the demands of the different sectors active in the region.

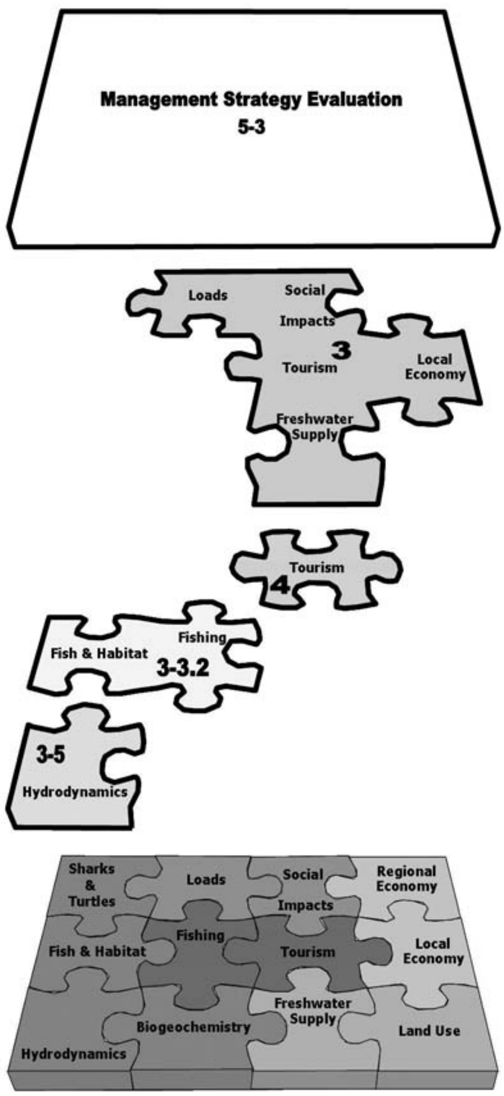

Figure 1.

The information jigsaw – the range of models and the components of the Ningaloo system that they capture.

Figure 2.

The adaptive management cycle (Jones 2005)

Management Strategy Evaluation

Management Strategy Evaluation (MSE), or Operational Management Procedures (OMP) as the method is also known, is a simulation technique based on modelling each part of the adaptive management cycle (Figure 2). It was originally developed more than 20 years ago to consider implications of alternative management strategies applied to natural resources (e.g. fish stocks). The method is now widely accepted as a best practice approach for single stock and ecosystem-level management questions and has recently been adopted for multiple use questions as well. The MSE approach is used both by international bodies such as the International Whaling Commision (e.g. IWC 1992, Kirkwood 1997) and CCAMLR (de la Mare 1996) and national fisheries departments - e.g South Africa (Punt and Butterworth 1995, Cochrane et al 1998, Butterworth et al 1998); Europe (Horwood 1994, as of Butterworth and Punt 1999); New Zealand (Starr et al. 1997) and Australia (Punt and Smith 1999). A detailed review of the history of the technique is beyond the scope of this paper, but interested readers are referred to two very useful reviews of the subject by Butterworth and Punt (1999) and Sainsbury et al. (2000).

The strength of the MSE approach is that it does not try to find some optimal solution based on a single model. Instead alternative hypotheses (typically management strategies) are evaluated using multiple candidate models that include a representation of each step of the adaptive-management approach. The consequences of the alternate hypotheses can then be evaluated across the models to check for the robustness of the results. The other key strength of the MSE process is that it is consultative – all interested parties can have input into the candidate models and management scenarios. Effectively the MSE becomes a ‘flight simulator’ to help people interested in a system understand its potential responses to proposed actions and their associated tradeoffs.

Methods

InVitro

The MSE model used for Ningaloo is ‘InVitro’ (Gray et al. 2006). This is a 3D process driven whole of ecosystem model (that is it spans biophysical and human components) that uses a hybrid agent-based modelling framework. That is it combines classical differential equation models (typically for physical or lower trophic level components) with individual-based models (for the higher trophic levels and humans). It includes the dominate components of the natural system as well as a wide range of human activities on a regional ecosystem, including fisheries, tourism, oil and gas, salt production, coastal development and infrastructure, ports, shipping, regional economics, catchment use, recreation and conservation. To allow for a high degree of flexibility and to facilitate the handling of uncertainty the modelling framework uses a modular design.

In practice, model construction depends upon tradeoffs between model complexity, available data or knowledge and computing resources. The range of processes and sectors included in the Ningaloo implementation of InVitro is given in Figure 3.The biophysical system components included include all of the dominant system components (primary producers, benthic habitats, benthic invertebrate communities, pelagic forage fish, main target species of fin-fish and crustaceans, top predators, and species of special interest like turtles). The behaviour of each of these components is specific to their type, such that mobile agents may be represented as individuals (e.g. whale sharks), or small groups (e.g. schools or sub-populations of finfish). In contrast, sedentary habitat defining agents represent entire patches, (for example seagrass meadows or areas of reef divided into slope, crest, lagoon and bombies). It is even possible to vary the representation through the life history of an animal (patches of

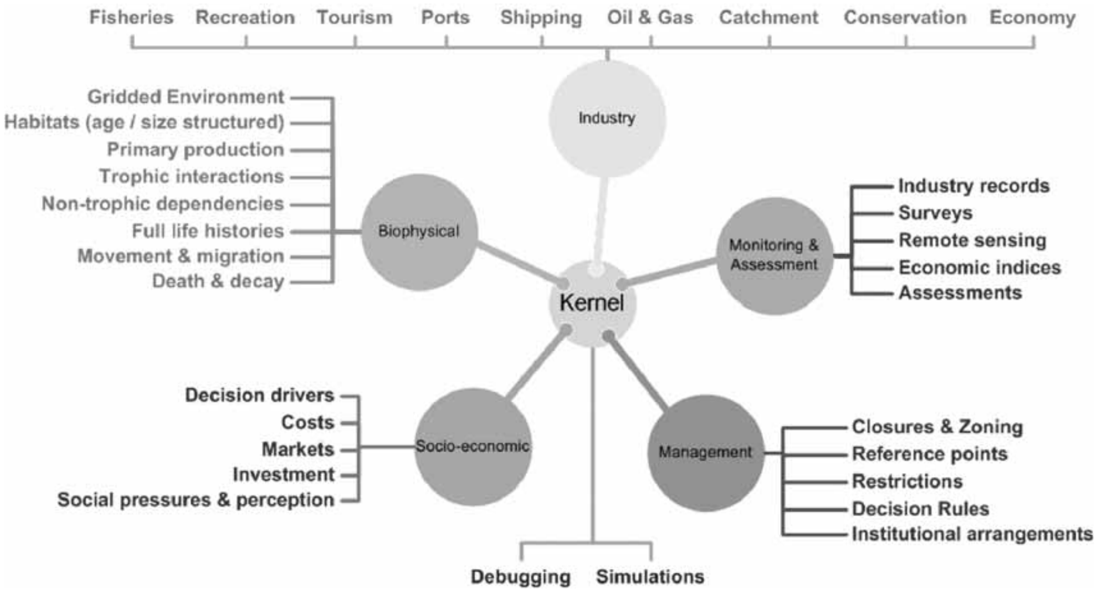

Figure 3.

Main components included in the Ningaloo-InVitro model.

larvae, schools of juveniles, individual adults). This ecological structure is set within a continuous, three-dimensional environment model defined by bathymetry, currents, temperature, light intensity, chemical concentrations, and wind. The individual ecological components respond to these characteristics, as well as habitat and other community members.

The sector sub-models in InVitro employ the hybrid structure to make the best use of existing representations of the different sectors. In practice, this has meant that sectors like fishing and tourism are more detailed than other industries models (such as that for oil and gas exploration, which uses an empirical scenario model to represent alternative future development scenarios). To date most of the work on the Ningaloo model has focused on the implementation and calibration of the biophysical model. Over the last year work on the human sectors has increased, particularly for the recreational fishing and tourism components. Work on the remaining human components will take up the next 1.5-2 years before the final simulations are run. In the interim, evaluations that only require a subset of the model (or are based on historical data only) will be run to give insight into the biophysical function of the system (e.g. the movement dynamics of fish) as well as targeted questions regarding compliance.

Results and discussion

An example of the kind of question that can be addressed with Ningaloo-InVitro is an evaluation of the implications of different levels of growth in tourist visitor numbers versus differing degrees of investment in infrastructure. In summary the dynamics of the system are such that:

- the main target species are habitat dependent
- visitor types can be defined based on their preferences (for accommodation types and activities), budget and trip length
- accommodation types are characterised by their type, price and sustainability
- regions are defined based on what activities, accommodation and infrastructure they contain
- activities are defined by their type, magnitude (how many people can do that at one time), duration, price, output and impact
- the most common type of tourists prefer to use sites that are easily accessible and have existing infrastructure
- tourists spread information (e.g. on the quality of their experience) by word of mouth
- increasing visitor numbers increases load
- without extra infrastructure pollution (or other stressors) lead to a deterioration of the habitat
- changing habitat leads to the loss of some species (e.g. large sharks) and a turnover in other species (with the resulting community made of species that are not as appealing to the main tourist type)
- tourists visiting after the deterioration has begun move to new sites that better match their preferences and pass this information on at accommodation nodes (e.g. Exmouth)

Interestingly some forms of management can lead to similar shifts in the popularity of certain sites, which has its own flow on effects with regard to infrastructure needs and biological, social and economic impacts.

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Qualitative modelling for sustainable tourism development in Ningaloo Park

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Abstract

Qualitative modelling is being employed to provide a synthesis of research projects for sustainable tourism development in Ningaloo Marine Park, WA. A series of models are presented that demonstrate how different aspects of tourism affect and are affected by the coastal and marine resources in the park. This modelling effort is being used to integrate ecological and socioeconomic systems related to tourism. In this overview, system feedback is analysed to demonstrate how a system dynamics may be understood across varying levels of model complexity.

Project description

Embedded within CSIRO's Wealth from Oceans National Research Flagship Collaboration Program is a cluster of research projects that are focussed on delivering support for multiple use management of Western Australia's Ningaloo Reef. A main objective of these projects is to integrate social and economic considerations into sustainable tourism development for the region. This objective is being achieved through a number of modelling efforts, including biophysical models of coral reef and lagoon systems, impacts of recreational fishing, and the distribution and economic impact of tourist activities through the Ningaloo region. This project will use qualitative modelling to provide rapid integration across these research projects and a synthesis of the key patterns, processes, and responses of the Ningaloo region. This approach will be used to provide a conceptual framework to elicit stakeholder involvement, knowledge and understanding, and it will be used to complement the other modelling efforts that are quantitatively based.

Qualitative modelling can be used to address uncertainty in how ecological and socio-economic systems are structured, and explore different hypotheses about key processes and interactions among system variables. This modelling approach focuses on the sign (positive, negative or zero) of interactions between variables, which thus defines model structure. Using qualitative mathematics to analyze system feedback, these models provide understanding about the key drivers and regulators of a system, and makes predictions of how variables will respond to a perturbation (increase, decrease, or no change). By ignoring the strength of interactions, the analyses instead focus on the structural uncertainty of a system and can be used to rapidly explore the consequence of different model structures.

A key step in model building is the process of elicitation of knowledge from stakeholders and experts to define the context of the problem and thus the model's domain and purpose. Typically this involves construction of a series of causal connections that link an event or process to an impact and it is common for this construction to be based on the conceptual framework of experts in the field of interest. It often arises that there are competing ideas about how the world works, either from uncertainty within a single individual, or where multiple experts disagree about specifics of the model system. This uncertainty can take the form of disparate degrees of aggregation in state variables, the causal links between variables, and even the hierarchy or level of organization at which a process or the system is being described and modeled. Here we attempt to formally capture the details of this variation so that different constructs of a system can be formally considered.

The construction of qualitative models is based on a graphical representation of system variables, processes, and interactions, and thus it lends itself to more a more easily grasped and intuitive understanding of system structure, function and dynamics. Knowledge from stakeholders can be integrated with that of experts, thus increasing stakeholder involvement and understanding of the modelling process. Moreover, their understanding and trust can be extended to more complex and quantitatively based models where the models have been informed and complemented by qualitative models to which the stakeholders have contributed.

Current findings

An array of qualitative models has been developed based on the systems underlying the focus of the research projects. Here we present a general overview through models from a selection of three areas of research.

General models of tourism

In Figure 1a is a sign digraph of a general model of tourism which shows how tourists (T), supporting facilities (F) (e.g., hotels, restaurants, camp sites, roads, boat ramps, etc.), and the environment (E) interact. The links between variables denote direct effects. Positive effects are shown by links ending in an arrowhead, and here denote attraction to resources or services or investment of profits. Negative effects are shown as links ending in a filled circle and denote

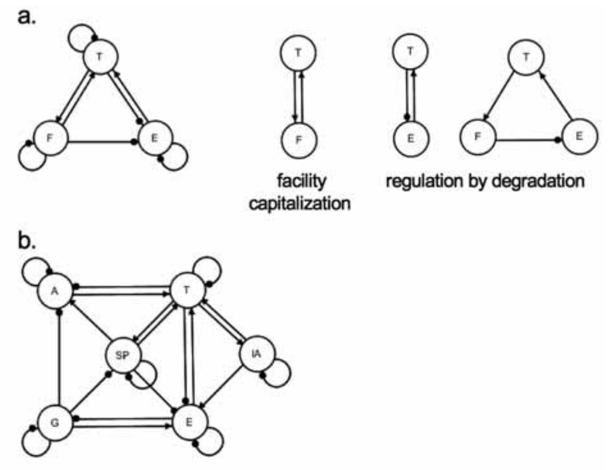

Figure 1.

Qualitative models of environmentally-based tourism with a relatively a) simple and b) intermediate level of complexity. For the model in a) feedbacks between tourists (T), facilities (F), and the environment (E) act to both drive and regulate the system's dynamics through the processes of capitalization and environmental degradation. The model in b) includes variables describing relationships between accommodations (A) e.g. resorts and hotels, service providers (SP), e.g., tourism operators, impact attenuation (IA), e.g., sewage treatment plant, and governance (G).

degradation or removal of a resources. Here tourists numbers support and are supported by facilities, and are a function of the quality or amount of resources supplied by the environment. The environment is degraded, however, due to impacts from both the tourists (e.g. recreational fishing, reef walking, dune sports, camp sites, etc.) and the supporting facilities (e.g. boat ramps, roads, tour operators, hotels, etc.). In this model there are three feedback cycles that control the system's dynamics (i.e., a feedback cycle is a series of links that form a causal path leading from a variable, through other variables, and back to itself, its overall sign is calculated by simply multiplying the sign of the links along the path). A positive feedback occurs through capitalization, where investment in supporting facilities supports additional tourist, which provides increased reinvestment. This process drives the tourist-facility subsystem forward, but at a cost to the environment, and the whole system is brought to an equilibrium by the regulating effects of two negative feedback cycles.

It is easy to criticize the model in Figure 1a for being overly simplistic, as it leaves out many details known to be important to environmentally-based tourism, let alone a context close to the Ningaloo Marine Park. But the feedbacks and dynamics of this simple three variable model can still be instructive, and used as a basis for understanding the behavior of larger more

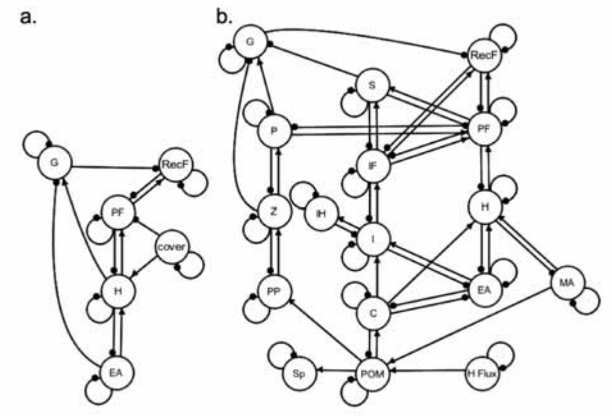

Figure 2.

Qualitative models of coral reef ecosystem for Ningaloo Marine Park. The model in a) conforms to results from specific experiments that documented impact of recreational fishing (Westera, M. 2003. PhD thesis, Murdoch Univ.), while the model in b) includes additional trophic groups and interactions (pers. com., Chris Simpson and Kelly Waples); cover: protection from predation provided by coral, C: coral, EA: epilithic algae, G: governance, H Flux: hydraulic flux over reef crest, H: herbivorous fishes, I: invertebrates, IF: invertivorous fishes, IM: invertebrate harvest, MA: macroalgae, P: planktivorous fishes, PF: piscivorous fishes, POM: Particulate organic matter, PP: phytoplankton, RecF: recreational fishing, S: sharks, Sp: sponges, Z: zooplankton.

complex models. In Figure 1b the facilities variable (F) has been replaced with variables describing accommodations (A), service providers (SP) and public works that attenuate impacts (IA). These substitutions create a number of positive feedbacks that can be viewed as variations on a theme from the simple model. For instance, there are three positive feedbacks cycles associated with tourism that can be categorized as facility capitalization (i.e., T→SP→T, T→SP→A→T, and T→IA→E→T). The introduction of governance (G) into the model is design to provide regulation via a means other than degradation. Here the level of governance is determined by research or monitoring that measures the state of the environment. This is treated as a negative link from E to G, such that when the quality of the environment is good there is less impetus for governance to curtail or limit the activities of A and SP. As before, regulation still occurs through negative feedback cycles associated with degradation (i.e., E→T→E, E→T→SP→E) but now also through four additional negative feedbacks that involve governance (i.e., G→E→G, G→SP→E→G, G→A→T→E→G, G→A→T→SP→E→G). There is also a novel positive (or capitalization) feedback associated with governance (i.e., G→A→T→IA→E→G), that promotes economic growth while also assuring investments in public

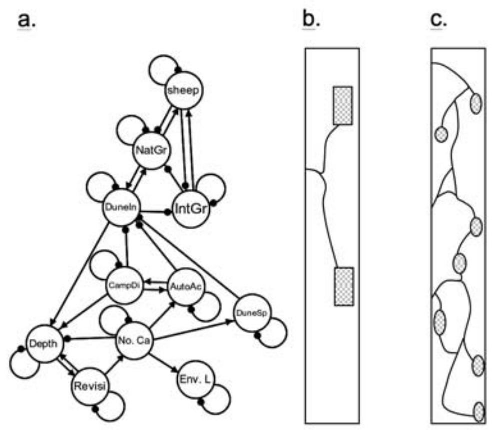

Figure 3.

a) Qualitative model of tourist use and impact on the terrestrial environment of Ningaloo Marine Park, with depiction of a relatively b) low and c) high level of dispersion for road-accessed camp sites (stippled areas) in coastal sand dunes. AutoAc: automobile access in dunes, CampDi: camper dispersion, Depth: depth of positive experience for tourists, DuneIn: dune integrity, DuneSp: dune sports (sport vehicles, sand-boarding), Env. L: environmental load, IntGr: introduced grasses, NatGr: native grasses, No. Ca: number of campers in dunes, Revisi: rate of tourist revisitation, sheep: sheep stocking level.

works that preserve the quality of the environment are commensurate with investments in tourist accommodations. A critical link in the dynamics of this model is the research and monitoring link E→G. If this link is weak or absent, then the system will be regulated solely by environmental degradation.

Fishing impacts on a coral reef ecosystem

An important management issue for the Ningaloo Marine Park is to allow a sustainable recreational fishery that has limited impacts to the coral reef ecosystem. One aspect of this problem has been documented in experiments which found that high levels of harvest of piscivorous fishes resulted in a trophic cascade, whereby a concomitant increase in herbivorous fishes reduced the amount of epilithic algae on the reef. This effect appears to have been buffered by the degree to which coral cover was present at particular sites. A simple model that reproduces these results is presented in Fig. 2a. And these results can be extended to pose an effective management system, where monitoring of the levels of herbivorous fishes and epilithic algae allow effective governance of the intensity of fishing permitted in the park. Note that in the model of Fig. 2a the feedback cycles involving the governance variable are all negative and thus stabilizing. Here again, though, it is easy to criticize this model for what is left out, and a range of alternative more complex models are being consider in this project. In Fig. 2b is a model with more detailed trophic interactions. An interesting feature of this model is that it is difficult to reliably distinguish effects of fishing from other impacts to the system, such as changes in productivity, when monitoring only herbivorous fishes and epilithic algae. A more reliable signal for fishing effects appears to come from monitoring other trophic groups such as sharks or planktivorous fishes. These results, however, are preliminary, and are being investigated further through alternative models and discussion with other research projects.

Camping impacts on sand dune integrity

Research projects on land use along the sand dunes of Ningaloo Park will be trying to understand how tourists respond to the quality of the dune environment as well as their effect on it. Here qualitative modelling has been employed prior to commencement of field work to summarize existing knowledge and to help distinguish what aspects of the system are most uncertain or appear to be the most important to model dynamics. The model in fig. 3a is a first attempt at describing the system. In addition to tourist activities and perceptions, it attempts to incorporate the effects of grazing, non-native vegetation. A key feature of this model is the effect of camp site dispersion (Fig. 3 b and c), which affects both the quality of the camping experience and sand dune integrity. This model will be revised according to information gained from ongoing field studies.

Next stage

Future work for this research project will seek to integrate the various modelling efforts in the Ningaloo research cluster. One such need is to describe how tourist impacts on the environment feedback to the socio-economic constraints that are used in the tourist destination/load model. Additionally, this project will involve the use of qualitative models as tools to engage with stakeholders so as to elicit their knowledge and understanding of the system, and to increase their understanding of the various research projects currently underway. An complementary extension of this work will involve mapping of the social networks of researchers and stakeholders, so as to identify critical communication gaps.

Acknowledgements

We thank Karin Shianetz, Todd Jones, Pippa Chandler, Anna Lewis, Chris Simpson and Kelly Waples for their help in the development of models presented in this work.

Rapid assessment of scenario outcomes for natural resource management

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Abstract

We describe ScenarioLab, a tool to rapidly assess the impact of management decisions on fish populations under different scenarios. In this case the scenarios characterise the Ningaloo Marine Park. Each stage of the modelling process is controlled by graphic user interfaces which allow comparison of the outcomes of multiple runs of an ecological and management model and to decide what further modelling is needed.

At the core of this method lies the belief that the management program may not need to be set a priori, rather may emerge as a result of the interaction between different parties, which ScenarioLab may facilitate. We envisage that a team including managers and stakeholders (rather than a single expert user) may employ this approach as an avenue for communication, leading to exploration and discussion of the conflicting aspects of different model outcomes.

For this to be possible the tool needs to a) be intuitive enough to be comfortably controlled by non-expect modellers, b) run very fast so that the results can be computed in almost real-time, c) provide for a flexible way to define the suitability of a strategy outcome and d) allow modification of goals at any stage of the process, as a result of the information provided and the discussion it generated. All implementation and software design decisions have been made in order to accommodate the above points as main priorities. These are discussed in more detail below.

Project description

Two principles are at the base of ScenarioLab. First, the evaluation of a modelling outcome is subjective and contextual: different users may judge an outcome differently depending on their expectations, needs, assumptions and expertise. Since assumptions, like expectations and expertise, may change as a result of the modelling results, the evaluation of a modelling outcome may change during a ScenarioLab session. Second, humans find it easier to express relative judgments ("*model outcome 3 is worse than model outcome 7 but better than model outcome 2*") than absolute ones ("*model outcome 3 is the fourth best among all runs*").

These two principles have been the main driver for the development of ScenarioLab's graphical user interfaces (GUI) which enable to control and evaluation of different model runs *in parallel* and to direct future modelling iterations.

The description of the GUI clarifies the approach. Figure 1 shows a snapshot of a ScenarioLab's iteration. You can see 3 panels, a green one on top and a red and a blue one at the bottom. Within the green panel you can see 4 smaller grey panels named Scenario 1-4. Each Scenario panel displays the outcome of an independent run of our numerical model. As an example, let's analyse Scenario 1. The plot displays 2 sets of time series; for a given species, the red time series show the evolution of the biomass through time, while the black ones indicate the catch. Each set of time series consist of 3 time series describing the behaviour of the species under different model specifications; this is done in order to capture to some extent the inherent uncertainty in the model parameterization. By playing with the drop down menus above the plot the time evolution of all modelled species in all modelled zones can be displayed.

On the right hand side of the plot a white window called 'Man. Options' shows the specifications of the individual run which generated the output we just described. Such specifications represent the management decisions whose outcome we wish to evaluate. Notice that each field is editable, that is the user can change any management input at any time and re-run the model in order to analyse the impact of the change.

On the top left, just under the writing 'Scenario 1' there is another drop down menu, currently displaying 'Not ranked'. Via this menu the users can provide a *subjective* and *relative* evaluation of the suitability of the model outcome. The evaluation is relative in the sense that the model outcome is compared to the outcomes in the other 3 Scenarios; against which the current model can be judged as 'best', 'worst' or somewhere in between. The evaluation is also subjective because it is obtained by assessing various aspects of the model results and depends on the users as well as on the purpose of the modelling exercise. In the case of multiple users we expect that the ranking of the model outcomes will involve discussions with exchange of ideas and information.

Finally, in the red panel at the bottom left hand side another Scenario panel is displayed. This represents the best outcome among all models run so far. This panel has two roles: first it ensures the best result obtained so far is not lost and second it provides a link, and thus continuity, between the different iterations in ScenarioLab.

Now that we are familiar with the basic options available we can describe a typical modelling exercise. At first the model is

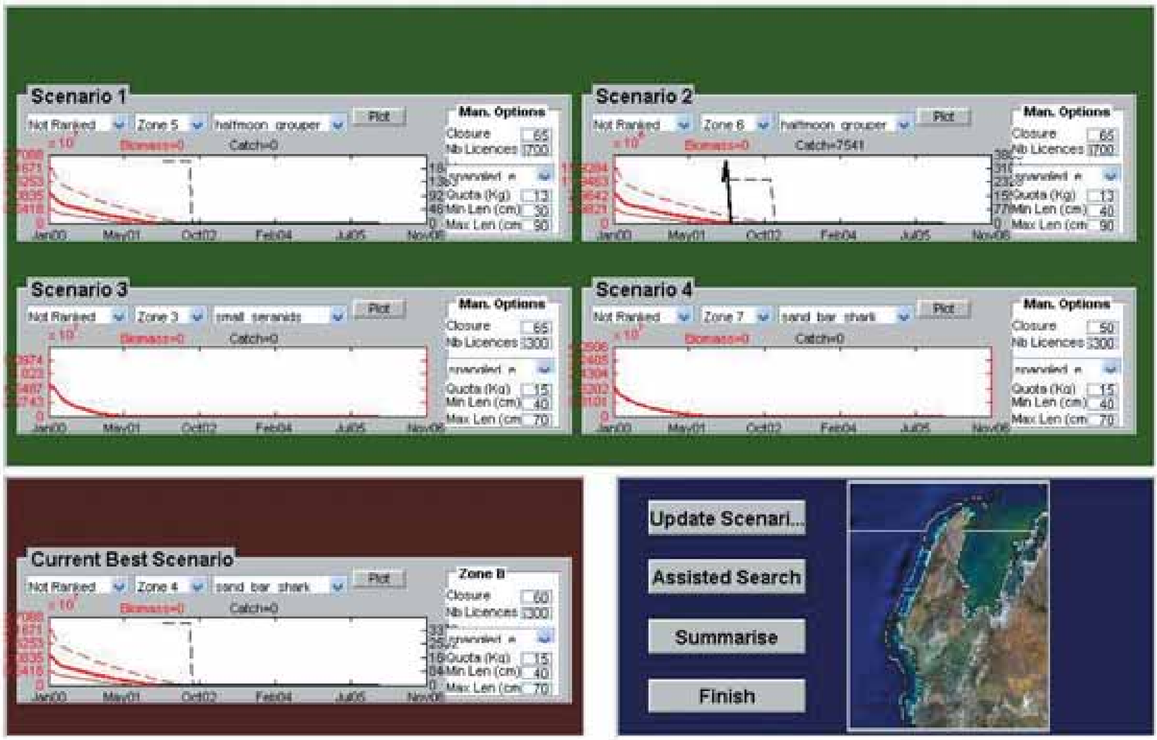

Figure 1.

Typical ScenarioLab GUI.

run with 4 initial model specifications (which can be chosen randomly) and the 4 outcomes are displayed in the 4 Scenario panels. After careful inspection of the results, which involves analysis of the biomass and catch time series for different species and different ecological zones, the users have 2 options. If any scenario generated insights worth pursuing, such scenario can be investigated further in a 'what-if' approach. This can be achieved by manually changing some of the management decision input in the 'Man. Options' white menu and the scenario is then re-run in order to analyse the impact of such decision. Alternatively, the users can decide to provide an evaluation of the quality of the results via the drop-down raking menu. This ranking is then passed to a a numerical optimisation routine which generates new model specifications to run accounting for the users' feedback and tries to explore management options similar to the ones currently described as 'good'.

The process is iterated until the users feel a satisfactory picture of the problem is obtained. Notice that the criterion according to which a model run is judged is not fixed and can change during the iterations, that is, can change as a result of the insights and learning which occur during the process itself. This is an extremely powerful feature, both conceptually and practically, which goes beyond the classic view of a model as a fixed and closed system. It enables the users to do what there are best at, that is to provide judgement, insight, intuition and even ethical concerns, and to make the most of the only thing a computer does well: fast computation.

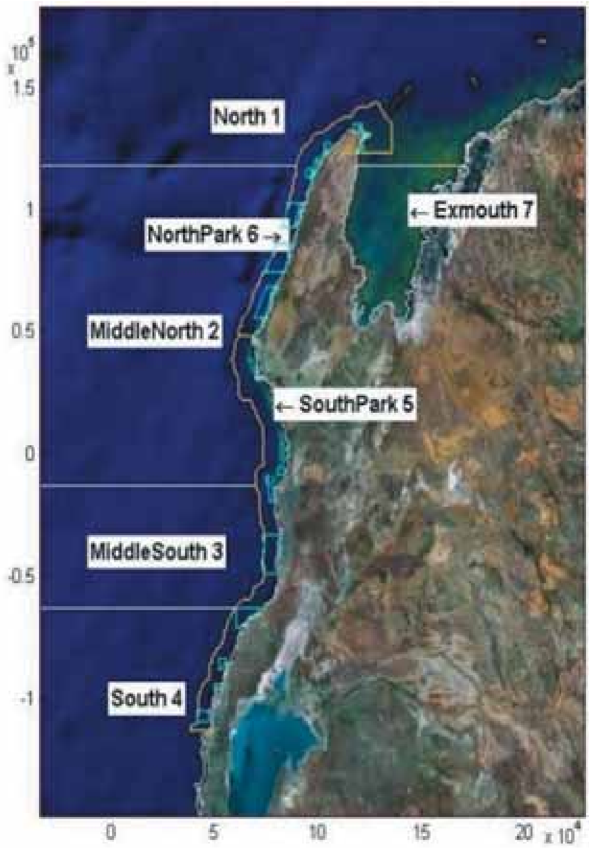

Figure 2.

The studied area and the ecological/fishing zoning.

Current findings and their implications for management

ScenarioLab's development is currently on-going and here we describe the status of each component.

Spatial setting; this implementation of ScenarioLab is based on Ningaloo. The geographical setting and zoning of the studied area has been chosen in accordance with both ecological and administrative constraints and is displayed in Figure 2. The Ningaloo Marine Park has been arbitrary divided into two zones and its boundary roughly separates a shallow from a deep water environment. Outside the park the zoning correspond to existing fisheries regulatory zones. Finally, a separate zone is assigned to the Exmouth Gulf, because of it has a different foodweb.

Ecological module; this accounts for trophic relations among different species; at present five fish species within a 3-level food-web are modelled, but this can be extended if needed. Three types of foodweb are used in order to discriminate between the different ecological zoning. The species included in the foodwebs have been chosen via consultation with biologists both in CSIRO and WA Fisheries. Species are modelled as populations and their behaviour described via non-spatially explicit differential equations.

A fishing module; this models the fishing behaviour, including: the access to the fishing zones; the sharing of the catch among vessels targeting the same zone; and the choice of the target species.

An economic module; this models the fishers' decision making; fishers store their past record of catches and choose which fishing zone to target according to a prediction of what the most profitable zone might be in the next iteration. Vessels act as individual agents in deciding what fishing zone to target, while their fishing behaviour is population-based for computational reasons.

A fishing regulation module; this defines the fishing regulations at each fishing zone and represent the input to the model which the management team can manipulate. These include the extent of sanctuary zones, the number of fishing licences allowed, and the quota, legal minimum and maximum length for two species of interest Spangled Emperor and Chinaman Cod. The module can be extended easily to include other regulatory criteria.

A management tool comprising the Graphic User Interfaces discussed in the previous section.

A summary visualisation, which generates a synthesis of the results from all individual runs of the ecological model during a Scenario-lab session via multi-dimensional visualisation.

Knowledge transfer

ScenarioLab is designed for managers and stake holders and more in general for 'non-experts' who are interested in learning about and evaluating the potential of numerical modelling as a aid to decision making. it is an educational and demonstrational tool rather that a platform to generate reliable forecasts for which more sophisticated models like ELFSim and InVitro are better suited. We envisage that ScenarioLab will be a very useful tool for introducing managers and stake holders to the complexity of ecological modelling; and to quickly highlight the issues which deserve in-depth analysis (which should then be rigorously studied via models like InVitro and ELFSim).

Next stage

Currently ScenarioLab contains a reasonable amount of ecological and biological information from the studied area. A number of important variables are uncertain though, such as current fish biomass and recreational fishing effort. Reducing or accounting for such uncertainty will be the first priority in the coming research. Subsequently, because of its own nature, the development of ScenarioLab will depend mostly on the feedback from users, which will determine whether more modules (tourism, commercial fishing, etc) are developed or more emphasis is placed on the visualisation and the interpretation of the results.

Acknowledgements

The authors wish to acknowledge: CSIRO Marine and Atmospheric Research – Dr David MacDonald for the initial guidance which resulted in this approach; Dr Randall Gray for assistance on the development of the ecological model; WA Fisheries – Dr Daniel Gaughan, Dr Ross Marriott and Dr Peter Stephenson for providing data and regular feedback on the model and CSIRO Land and Water – Dr Geoff Syme and Ms Peta Dzidic (PhD Candidate) for useful discussions and feedback.

A demonstration of ELFSim for evaluation of line fishing management strategies on the Ningaloo Reef

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Abstract

Management Strategy Evaluation is a valuable tool for determining the effects of strategies used to manage a natural resource before they are implemented in reality. We have developed a spatially explicit age-structured population model, called ELFSim, to examine the effect of different management options in coral reef line fisheries. In its current form ELFSim can evaluate a range of management options including area closures, effort restrictions, changes to size limits and gear restrictions. A major strength of ELFSim is that it enables the spatial characteristics of the fishery to be scrutinised in detail. This applies to both spatial exploitation of the resource as well as the meta-population dynamics of the resource, and linkages via larval migration. We show an example of ELFSim results, how they are interpreted and their limitations. We are currently developing an individual based model to simulate the effects of recreational fishing, and have shown the effects of different marine reserve networks.

Project description

One of the big challenges for contemporary Australian society is the management of competing human uses of, and effects on, natural and transformed environment. 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. The past tendency to use scientific advice on an ad hoc basis, and to have it absorbed along with many other types of advice in an unspecified way, has prompted scientific research agencies to seek better ways of providing scientific support.

Among the barriers to uptake of scientific principles is a lack of a broad contextual framework within which non-scientists can assess the merits of particular scientific advice. It is to this broad contextual framework that scientists have turned their attention in attempting to communicate with a widening range of stakeholders. Such a framework requires active participation of stakeholders (including management agencies) and facilitates the generation of ideas, identification of problems and approaches for solving them, as well as anticipation of real-world effects. The framework necessarily spans diverse fields ranging from biophysical, social and economic sciences, to jurisdictional, political, institutional and managerial processes.

In response to the need for providing an appropriate scientific framework, CSIRO Marine and Atmospheric Research has developed an integrated management strategy evaluation (MSE) framework. The purpose of the MSE framework is to advance the science and tools used to characterise, monitor, predict and manage natural resources across time and space scales. MSE has been applied successfully to fisheries, and has recently been developed for providing scientific decision support for multiple use management of coastal regions and estuaries.

In the Ningaloo Reef Marine Park fishing is one of the major human activities affecting the marine environment. The MSE framework uses process-based age structured population model coupled to model of human fishing behaviour. This model, called ELFSim (effects of line fishing simulator, Mapstone et al., 2004, Little et al. 2007) is a decision support tool designed to evaluate the options available for managing the harvest in reef line fisheries. ELFSim contains several components, including output visualisation and run management, but the most important components are a spatially-structured biological model of the population dynamics of a targeted species, (e.g. spangled emperor) , and a model of fishing behavior. ELFSim operates at a monthly time step, and each simulation consists of two parts. The first ('initialization') step operates historically (historical period) using information from catch records, and the physical characteristics of the reefs, to determine the initial and present size of the population on each reef. Reef populations are then projected into the future (projection period) by subjecting them to simulated fishing pressure, which is, in turn, affected by user-specified management regulations. The management regulations available involve area closures (including rotational closures), changes to gear selectivity, minimum legal sizes for harvest, as well as the annual allowable effort for each of the fishing sectors.

Results from the model will provide a means to assess, test and ultimately improve the effectiveness of management and monitoring strategies for the key target species in the region. The aims will be achieved by bringing the broad range of physical, biological and socio-economic information and process understanding being developed through the NRP and the CSIRO Ningaloo Collaboration Cluster (CSIRO Wealth from Oceans National Research Flagship) into an integrated framework. This will facilitate collation and interpretation of data gathered both historically and through the NRP. It will also provide an effective interface with management through development of tools that directly address needs such as risk assessment, performance assessment, and management strategy evaluation (e.g. multiple-use zoning, fishing effort controls, new monitoring regimes).

Current findings and their implications for management

The Ningaloo Marine Park has been refined to 1 minute X 1 minute grids and the spatial and putative amount of Spangled Emperor, Lethrinus nebulosus, habitat for each grid has been assigned based on GIS intersections with mapped inter-tidal coral reef habitat. This value determines the population carrying capacity for each local population associated with a 1 minute X 1 minute grid (Figure 1). Biological data for Spangled Emperor have been compiled and implemented into the model. Currently only charter fishing data (2002 – 2006) have been obtained so these have been used for the initial runs of the model. We are still awaiting historical recreational and commercial fishing data. For simulation of management scenarios, the zoning of the marine park has been incorporated into the model, thus preventing (legal) fishing from occurring in the protected (Sanctuary) zones.

Charter fishing catch and effort data were obtained at a 5 minute X 5 minute spatial grid scale for the period from 2002 to 2006. These data were disaggregated to the 1 minute X 1 minute spatial scale of the sub-populations based on the amount of assumed habitat distributed among the 1 minute grid cells embedded in each 5 minute grid cell datum. For each grid cell also, catch and effort data were hindcast linearly back to 1965, the year in which fishing was assumed to have started. A more robust time series of historical catch and effort will be used once the recreational and commercial data become available.

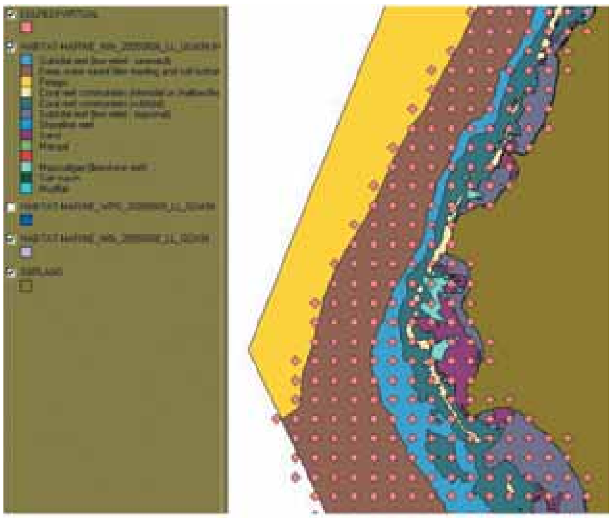

Figure 1.

Grid of putative Spangled Emperor sub-populations (red - diamonds) overlaid with benthic habitat in a portion of the Ningaloo Marine Park.

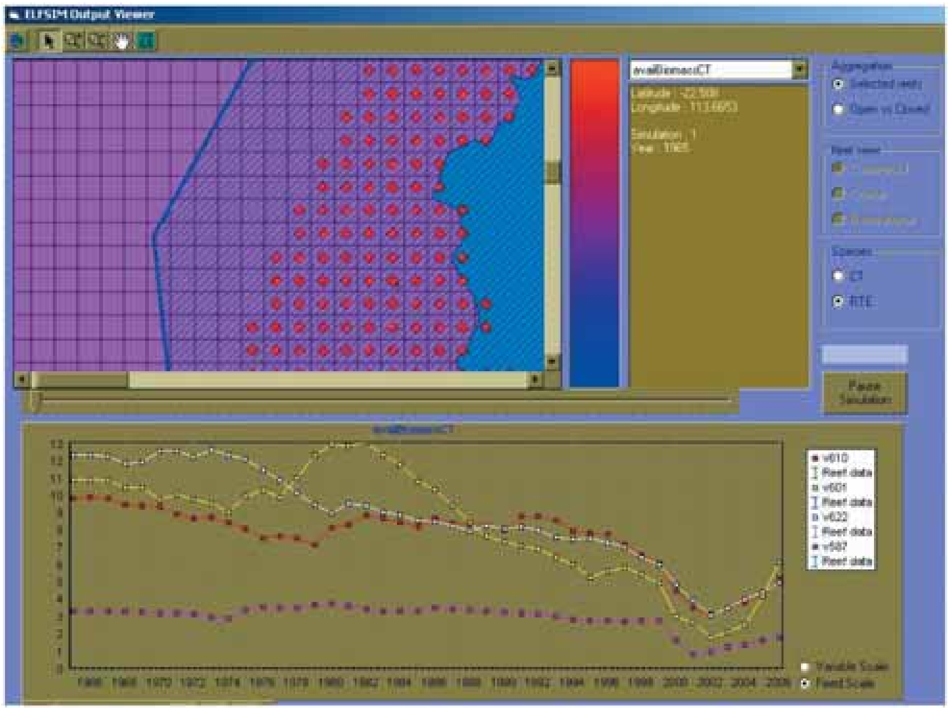

Figure 2.

ELFSim output viewer showing historical trends in Spangled Emperor available biomass on four local populations represented as 1 minute grid cells.

With the data we currently have, we are able to run the model historically, capturing the pattern (spatial) of historical fishing on the population. Assuming that there was no or little fishing occurring before 1965, and with an assumed relationship between habitat and reef (grid cell) population size, we are able derive the state of the local reef populations in 2006 (Figure 2).

At this point the model ceases to use historical data, and commences with projection of the fishery under different management regulations. Projection of the fishery involves simulating fishing practices on Ningaloo reef based on historical fishing data and any other data that is thought to influence fishing behaviour that might be available. The socio-economic data that might feed into this model of fishing behaviour is forthcoming from other projects, but currently a simple generic model of fishing behaviour is operational.

For simulation of management scenarios, the zoning of the marine park has been incorporated, so that fishing is prevented from occurring in the protected (Sanctuary) zones in the model of simulated fishing behaviour. Other management arrangements that can be examined include different zoning measures, different levels of enforcement/ infringement into closed areas, changes to minimum legal size, and gear selectivity, as well as controls on fishing effort and access. Figure 3 shows the effects on the biomass on the whole park of two different marine reserve scenarios, the current marine reserve / sanctuary network, and the one that existed prior to the current ones.

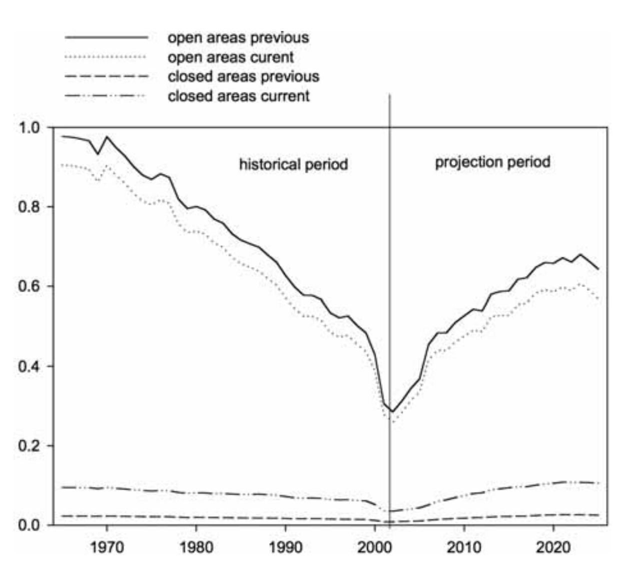

Figure 3.

Time series of available biomass (biomass that has recruited to the fishery, and would be legally retained if caught) in closed and open areas under 2 different closure scenarios.

The initial conditions in this scenario assumed historical fishing pressure depleted the spangled emperor population to about 30% of pre-exploitation levels. It must be stressed that ELFSim does not estimate this value, but rather assumes it, in order to show the effect of the implemented management strategies have under the specified conditions. Management strategy evaluations perform simulations under different scenarios, like that of a highly depleted population, moderately depleted population, and a relatively healthy population. Identifying management strategies that successfully achieve management objectives, and thus are robust to our uncertain knowledge of this system is one of the key goals of management strategy evaluation. This will be the approach for management use of this tool on Ningaloo reef.

Figure 3 shows the period in which catch and effort data deplete the population. The projection period of the model shows the effect on the population under the management conditions. In the case shown in Figure 3, the results show the long-term effect of using the previous, and the current area closure regimes. For the purpose of the model, the management conditions are assumed to be implemented at the beginning of the projection period. Thus the results show the long-term effects through time if one closure regime or another were implemented, and do not reflect the fact that the area closure regime changed.

Lastly, the detailed results in Figure 3 show a higher amount of closed areas protected from fishing under the current closure scenario. This however, comes at a cost to the open areas, which are smaller and thus have more concentrated effort. Current efforts in model development lie in developing a fishing effort model that realistically represents fishing effort behaviour, spatially. This model will incorporate bag limits, but will not attempt to model effort dynamics in the fishery as a whole. In other words, this model does not try to model how much recreational fishing effort is going to occur on Ningaloo reef in 2010. Nonetheless the model will allow us to explore the effects of non-compliance of fishing regulations like fishing in the no-take sanctuary areas. These issues are currently the important to the management of the fishery, which represents the main detrimental human activity to the ecological integrity of the marine park.

Knowledge Transfer

Integration with external research is core to the success of this sub-project. While the proposed modelling represents a new approach for the Ningaloo system, it necessarily builds upon a diverse range of physical, ecological, and socio-economic information collected in the past and within many of the projects listed in the Current Research Database for the Ningaloo Marine Park. It will also serve to integrate many of the outputs of the CSIRO ‘Ningaloo Cluster’ into a broader management strategy evaluation framework for the Ningaloo

Region. All data and metadata captured through this process will be made available across the NRP (unless confidential or embargoed e.g. socioeconomic data relating to individuals).

Next Stage

Collaboration with WA Fisheries in model refinement and an intensive data collation is the next priority of this project, which will include integration of all the available catch and effort data for spangled emperor. Several workshops are scheduled in order to help WA fisheries managers and scientists refine the model, understand its output and limitations, as well as helping the model development team understand and use WA Fisheries data.

Acknowledgements

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Technology and data management

Comparability within long term data sets of coral condition when methodology has changed

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Background

Coral reefs are highly dynamic systems in which the frequency and intensity of disturbance is an important determinant of community structure (Connell et al. 1997). Although there is currently a great deal of research into coral reef ecosystems occurring worldwide, there remains an underlying lack of long term and in-depth data within mainstream science to adequately inform management of the status and trends of coral reef ecosystems (Bellwood et al. 2006). This limits the ability of agencies to audit the effectiveness of management strategies or relate the snapshot status of coral communities to factors affecting the recovery and resilience of coral reef ecosystems. Understanding of the conditions that promote recovery and resilience is essential for future effective management of the world's coral reefs, and this understanding requires comparison of long-term studies of reef responses to disturbance.

Such studies typically rely on measures of coral cover as an indication of community structure and health. However, estimates of percent cover can vary depending on methodology, and considerable effort has been invested in developing and comparing estimation methods appropriate for coral reef environments (Loya 1978; Weinberg 1981; Chiappone and Sullivan 1991; Aronson et al. 1994; Houk and van Woesik 2006). Further, the long time series required to monitor coral condition may result in changes to methodologies with advances in technology over time. This often leads to datasets that can not be used to make assessments over time.

In the case of coral monitoring, the coral reef line intercept (LI) method was commonly used up to the mid 1990's (Loya 1978; reviewed English et al.1997). Since the advent of relatively cheap and convenient underwater video cameras, point sampling (PS) methods have become widely adopted as they can provide accurate estimates of percent coral cover, species richness and diversity more quickly and with less effort than conventional LI methods (Aronson et al. 1994; Hill and Wilkinson 2004; Beenaerts and Vanden Berghe 2005). Various studies have found remarkable consistency between percent coral cover estimates obtained with most of the commonly used methods (Chiappone and Sullivan 1991; Beenaerts and Vanden Berghe 2005; Côté et al. 2005).

The potential for incongruity between PS and LS methods was first raised by Carleton and Done (1995) who examined whether there were significant differences in percent cover estimation of both branching corals and total live coral using PS and LI analysis methods. Possible differences relate to the decision rules whereby in LI a branching coral colony is considered to cover the length of transect tape from first branch to last branch whereas under PS the substrate under a sampling point within a large live colony might often actually be sand (visible between branches) or algae (growing on lower, older branch sections).

Project Description

We describe a difference in estimations between LI and PS methods detected from a long term data series in an area characterized by high cover of branching coral (ie acropora). This study took place at Bill's Bay, an embayment of the coastal lagoon of Ningaloo Reef, Western Australia. Monitoring sites in Bill's Bay have been surveyed at irregular intervals over the past 17 years, and several methodological changes have occurred during this period, including a shift from conventional in-water LI analysis by a diver of 2 x 25 m transects (1989, 1994; Simpson et al. 1993), through LI analysis of 3 x 50 m video transects (2000; Grubba and Cary 2000), to PS analysis of 3 x 50 m video transects (2006; Long 2007).

We compared PS and LI estimations of percent coral cover at three sites in Bill's Bay to assess the significance of this potential problem for assimilation of the long-term monitoring data.

The three sites (site 8, 12 and 17) are all in similar sheltered backreef environments in Bill's Bay. At each site, three 50 m transect tapes were laid out in parallel in an east-west orientation, ~20 m apart. A diver swam slowly (~10 m/min) along each transect, filming at maximum wide angle and with the camera positioned ~50 cm above the substrate, such that the transect tape was in view along the left side of the image frame. For the purposes of this study the following highly simplified series of benthic categories was employed during analyses: branching acroporids (=arborescent acroporids), branching non-acroporids, non-branching corals, not live corals (this final category included all other substrates).

PS analyses involved the sampling of twenty fixed points from fifty frames taken from regular intervals during the recording of each 50 m transect. The substrate occurring underneath each of the twenty points on each frame was classified into one of the four benthic categories. Two decision rules were tested during PS analyses: the conventional method (termed PS-normal or PSN) described in Page et al. (2001) in which points falling between branches were classified as non-branching corals, and a modified method (termed PS-modified or PSM) in which points falling between branches were classified as branching corals. A total of one thousand points was sampled for each 50 m transect. These data were then converted to percentage cover per category for each transect.

For LI analyses, the video was replayed at half normal speed on a wide-screen television, to facilitate best possible classification of the substrate under the transect tape. The length of transect tape occupied by each benthic category was recorded to the nearest centimetre. We used the decision rules employed by previous LI analyses of coral cover in Bill's Bay: specifically, when large branching colony morphologies were encountered, the intersection length of the entire colony was measured as one observation, and any substrates or organisms visible underneath or between the branches were ignored. The percent cover of each benthic category was then calculated for each transect.

Following square root transformation, the estimated percent cover of each benthic category along each transect was compared both between methods and across sites using univariate ANOVAs in which site and method were fixed factors, transect was a random factor, and transect was nested within site. Once method-related differences were detected, a post-hoc test (LSD) was used to investigate the significance of differences in mean estimations via pairwise comparisons. The relationship between PSN and LI estimates of branching acroporid and total coral cover for each transect was investigated using linear regression.

Current findings and their implications for management

Site 17 is a backreef reference site which in terms of coral cover appears to have been very stable over almost twenty years of observation (Simpson pers. comm.). Unsurprisingly, LI estimations of total coral cover at site 17 in 2006 were very similar to LI estimations from site 17 in previous years (2000 and 1989; results not shown). However, PS estimations of benthic cover of branching acroporids, branching non-acroporids, non-branching corals and total coral cover were frequently considerably different to the LI estimations along each transect, and this was the case across all three sites (Figure 1).

Analysis of variance across all sites showed that these method-related differences in cover estimations were significant in the case of branching corals (p<0.000) and total coral cover (p<0.000). No significant method-related differences were found in estimations of branching non-acroporids (p=0.444) or non-branching corals (p=0.289). Post-hoc pairwise comparisons across all sites showed that the LI

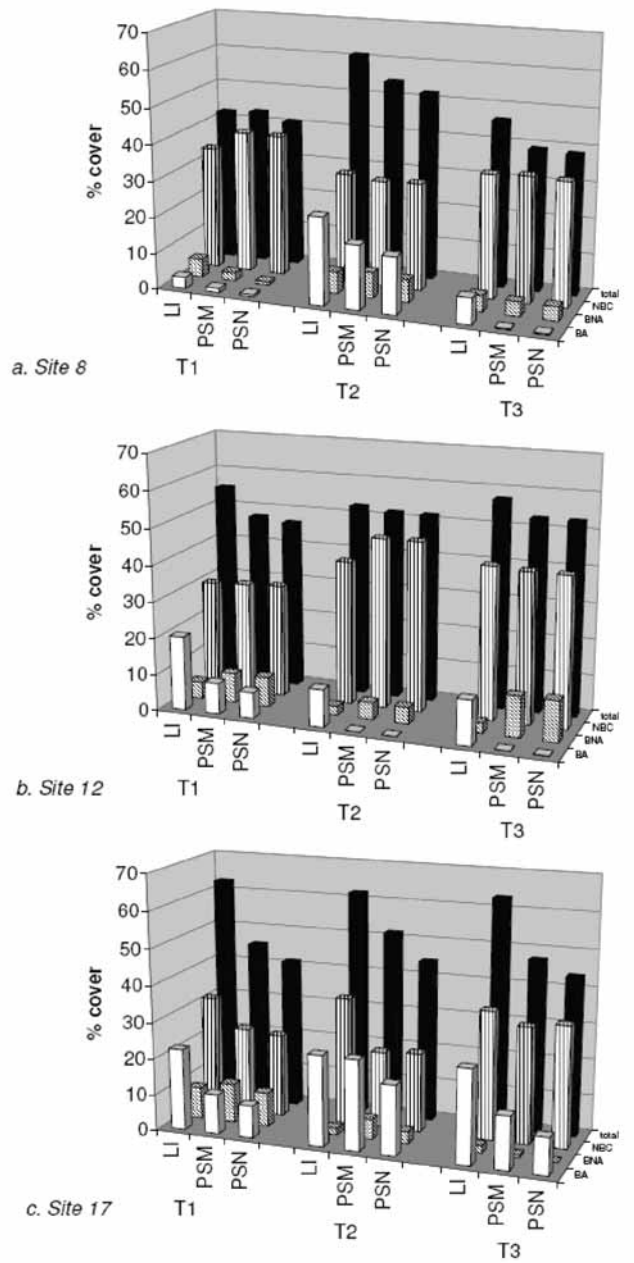

Figure 1(a-c).

Comparison between line intercept (LI), normal point sampling (PSN) and modified point sampling (PSM) cover estimation methods for three transects (T1, T2, T3) at each of three sites (site 8, site 12, site 17; a, b, c respectively) in Bill's Bay in 2006. BA = branching acroporids; BNA = branching non-acroporids; NBC = non-branching coral; total = total coral cover.

method significantly overestimated both mean branching acroporid cover (LI/PSM p=0.045, LI/PSN p=0.026) and mean total coral cover (LI/PSM p=0.014, LI/PSN p=0.003) relative to both PS methods.

By contrast, no significant differences were found between estimations of percent coral cover made using PS (Aronson et

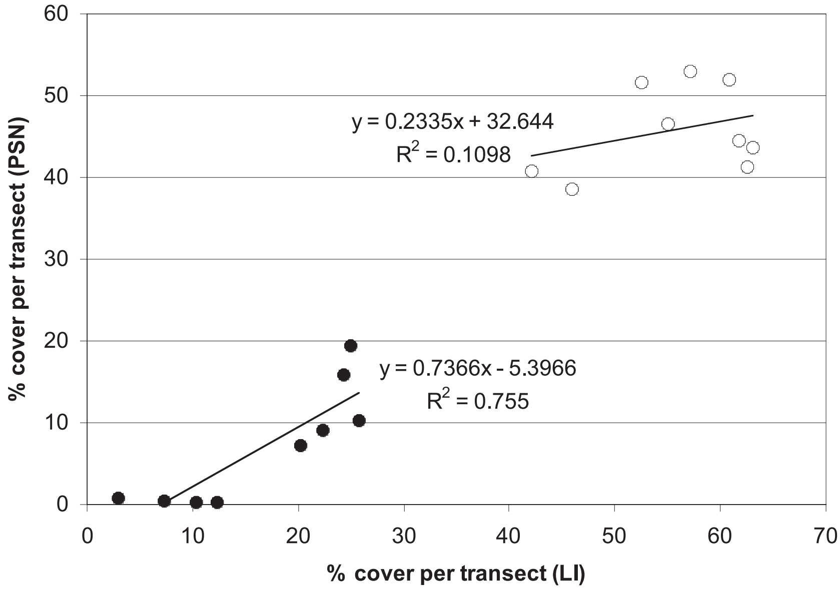

Figure 2.

Relationship between point sampling (PSN) and line intercept (LI) methods of cover estimation for branching acroporids (black circles) and total coral cover (white circles) along each transect at three sites in Bill's Bay.

al. 1994) and LI (Hughes 1994) at a site in Discovery Bay in Jamaica in 1992. However, this site had just ~3% live coral cover. Carleton and Done (1995) compared diverse methods of cover estimation at a site on the Great Barrier Reef with ~23% live coral cover including ~4.3% branching coral cover (estimated by PS methods). While their estimates of percent cover of branching corals derived from in-field LI methods were consistently higher than estimates derived from video PS, the difference between the two methods was not significant, and no significant differences were observed in estimations of total coral cover. This lack of significance could be due to the relatively high levels of variation between transects at their site (Table 6 in Carleton and Done (1995)).

As expected, PS-normal tended to underestimate cover of branching corals in Bill's Bay relative to PS-modified (Figure 1), but post-hoc tests found that the mean differences between methods were not sufficient to be significant. Although generally greater than PS-normal estimations, PS-modified estimations of branching coral cover, especially branching acroporid cover, were generally not equivalent to LI estimations (Figure 1). In fact the differences between mean estimations of LI and PS-modified methods remained statistically significant for branching acroporids ($p=0.045$) and total coral cover ($p=0.014$). Modification of the PS decision rules thus did not fully account for the observed differences in estimations between LI and PS-normal methods, even for branching acroporids. While the LI method always overestimated branching acroporid cover, cover of the other broad categories was sometimes underestimated and sometimes overestimated relative to PS methods. This indicates that additional factors, potentially unrelated to coral colony morphology, may be influencing LI estimation.

These analyses indicate that LI methods are likely to significantly overestimate cover of branching acroporids, as well as total coral cover, relative to PS methods. Although only likely to be important in branching acroporid-dominated habitats, these differences in estimates between sampling methods are non-trivial because of the importance of historical coral cover estimates as baselines for modern coral reef monitoring programs. In addition, acroporids are highly susceptible to disturbances relative to other coral taxa (Marshall and Baird 2000; Bellwood and Hughes 2001; Cleary et al. 2006), and trends in acroporid cover are often therefore used as indicators of both reef health and recovery processes. For example, branching acroporids were identified as the most informative morphological/taxonomic coral group for monitoring the impacts of diverse disturbances on coral communities in French Polynesia (Adjeroud et al. 2005), and also appear to be good indicators of reef recovery and resilience for diverse reefs in Western Australia (Long et al. unpubl.).

Similar methodological shifts are likely to have occurred at numerous locations worldwide as reef monitoring methods evolved over time. While this situation is far from ideal, the surprising dearth of long-term monitoring datasets for coral reefs in the scientific literature (Grigg 1995; Connell et al. 1997; Brown et al. 2002; Halford et al. 2003; Berumen and Pratchett 2006; Bruno and Selig 2007) and the apparently accelerating pace of global ecological change means that the relatively long time series of coral cover data from Bill's Bay is unusual and of potentially great scientific interest.

In the case of Bill's Bay, replacement of LI methods (used for surveys from 1989-2000) with PS methods (used in 2006) resulted in an apparent but artefactual decline in estimates of total coral cover of a startling ~19% at site 17 (mean 2000 (LI) = 60%, mean 2006 (LI) = 62%, mean 2006 (PS) = 43%). While coral cover is undeniably declining at most reefs worldwide (Bruno and Selig 2007), the results of this study suggest extra caution be employed when comparing historical (often LI-derived) estimates of coral cover with contemporary (often PS-derived) observations.

Knowledge transfer

This finding will be relevant to coral reef researchers and managers attempting to assimilate results from long-term reef monitoring studies in which there have been methodological changes over time.

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Discovery and access to WA marine data – WA node of AODN

Luke Edwards

iVEC, Curtin University, Bentley, Western Australia

WAMSI (Western Australian Marine Science Institution), iVEC ('hub of advanced computing in Western Australia') and WASTAC (Western Australian Satellite Technology and Applications Consortium) have teamed together to employ a Marine Information Officer [Luke Edwards] to assist with the establishment of the WA Node of the Australian Ocean Data Network (AODN).

It will provide a data management solution for WAMSI data and information while also providing a resource for other marine researchers to securely store and make their data accessible under agreed custodial arrangements that will provide a lasting legacy of marine data access and sharing in WA.

The WA node will be physically located at iVEC and will use the Metadata Entry and Search Tool (MEST) developed by BlueNet (and demonstrated at last year's symposium) to create metadata for WAMSI data and other WA marine data that is being archived.

Luke is available to assist any researcher get metadata loaded and accessible via the MEST; get data loaded and validated; assist with QA/QC data. The resources iVEC has at its disposal means it can easily store and handle large marine datasets such as hyper spectral data, video footage and model output.

If you would like to use this resource to secure your valuable Ningaloo research data please contact Luke on the details below.

Luke Edwards - Marine Information Officer
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Appendices

WAMSI node 3
Project list

Node Leader - Dr Chris Simpson, DEC

Reference	Title			
3.1	**Biodiversity assessment and development of cost-effective monitoring protocols**			
	Project Leader: *Andrew Heyward AIMS*			
	Subprojects:			
	3.1.1	**Deepwater communities at Ningaloo Reef**		
		3.1.1a	*Deep water habitat types*	*Andrew Heyward, (AIMS)*
		3.1.1b	*Fish biodiversity associated with habitat types in sanctuary and adjacent zones*	*Euan Harvey, Ben Fitzpatrick, (UWA)*
		3.1.1c	*High resolution data on cross shelf bathymetry and sediment facies*	*Rob McCauley, Emily Twiggs, (Curtin)*
		3.1.1d	*Species inventory database for Ningaloo deep waters*	*Jane Fromont, (WAM)*
	3.1.2	**Methods of monitoring the health of benthic communities at Ningaloo Reef**		*Martial Depczynski (AIMS)*
	3.1.3	**Stock assessment of target invertebrates at Ningaloo reef**		*Martial Depczynski (AIMS)*
	3.1.4	**Local and regional migratory patterns of whale sharks at Ningaloo Reef**		*Mark Meekan (AIMS)*
	3.1.5	**Ningaloo Research Program start-up project for physical oceanography of the Ningaloo Marine Park**		*Richard Brinkman (AIMS)*
3.2	**Biodiversity assessment, ecosystem impacts of human usage and management strategy evaluation**			
	Project Leader: *Russ Babcock CSIRO*			
	Subprojects:			
	3.2.1	**Diversity, abundance and habitat utilisation of sharks and rays**		*John Stevens (CSIRO), Peter Last (CSIRO), Rory McCauley (DoF)*
	3.2.2	**Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation**		*Russ Babcock (CSIRO)*
		3.2.2a	*Broad scale fish surveys*	*Russ Babcock (CSIRO)*
		3.2.2b	*Intertidal invertebrate species*	*Bob Black (UWA)*
		3.2.2c	*Assessment of trophic cascade effects*	*Glenn Hyndes (ECU)*
		3.2.2d	*Lagoon invertebrates (crayfish)*	*Russ Babcock (CSIRO)*
		3.2.2e	*Assessment of zone adequacy using fish tagging and tracking*	*Russ Babcock (CSIRO)*
		3.2.2f	*Finescale fish surveys – fish communities and habitats*	*Ben Fitzpatrick (UWA)*
	3.2.3	Management strategy evaluation		Rich Little (CSIRO)
3.4	**Characterisation of geomorphology and surficial sediments**			
	Project Leader:	*Prof Lindsay Collins (Curtin)*		

Reference	Title		
3.5	**Characterisation and modelling of oceanographic processes**		
	Project leader: *Prof Charitha Pattiaratchi (UWA)*		
	Subprojects:		
	3.5a	**Assessment of the dominant hydrodynamic processes in the reef lagoon system**	*Graham Symonds (CSIRO)*
	3.5b	**Numerical simulation of waves, currents, sediment transport and particle dispersion in a shallow complex reef environment**	*Ryan Lowe UWA)*
	3.5c	**Assessment of the near-reef oceanic processes on organism –scale nutrient dynamics**	*Anya Waite (UWA)*
3.6	**Science Coordination: Administration, communication and data management**		
	Project leader: *Chris Simpson (DEC)*		
	Subprojects:		
	3.6.1	**Science coordination and administration**	*Kelly Waples (DEC)*
	3.6.2	**Communications program**	*Communications Officer (DEC)*
	3.6.3	**Data management program**	*Data Management Officer (DEC)*
3.8	**Northwest Marine Research Inventory**		
	Project leader: *Chris Simpson (DEC)*		
	Project team: *Tim Skewes/Tom Taranto (CSIRO)*		
3.9	**Post-graduate seed funding program**		
	Project leader: *Chris Simpson (DEC)*		
	Subprojects:		
	3.9.1	**Deepwater communities at NMP and ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation**	Ben Fitzpatrick, UWA
	3.9.2	**Characterisation of geomorphology and surficial sediments**	Emily Twiggs, Curtin
	3.9.3	**The policy relevance of choice modelling: an application to Ningaloo Marine Park**	Abbie McCartney, UWA
	3.9.4	**Quantifying impacts of the Leeuwin current on the ecology and biogeochemistry of the Ningaloo Reef**	Cecile Rousseaux, UWA
	3.9.5	**The population dynamics and habitat usage of Sousa chinensis and Tursiops truncatus in the NMP**	Kristel Wenziker, Murdoch
	3.9.6	**Hydrodynamic processes in the Ningaloo reef system over a range of space and time scales**	Soheila Taebi, UWA
	3.9.7	**The role of microbial communities in reef building corals along the Ningaloo Reef, WA**	Janja Ceh, Murdoch
3.10	**Assessment of the groundwater system and its linkages to the NMP**		
	Project Leader: *Lindsay Collins (Curtin)*		

Wealth from Oceans National Research Flagship Program: Ningaloo Collaboration Cluster Project list

Cluster leader – Prof Neil Loneragan, Murdoch

WfO theme leader – Bill de la Mare, CSIRO

Project No.	Title		
1	**Habitats and biodiversity of Ningaloo Reef lagoon**		
	Project leader: *Mike Van Keulen (Murdoch)*		
	1.1	Hyperspectral mapping – Bathymetry	*Merv Lynch (Curtin)*
	1.2	Hyperspectral mapping – Habitats	*Halina Kobryn (Murdoch)*
	1.3	Biodiversity – soft corals, macroalgae and macro invertebrates	*Mike Van Keulen (Murdoch)*
2	**High resolution mapping of reef utilisation by humans at Ningaloo**		
	Project leader: *Assoc. Prof. Lynnath Beckley (Murdoch)*		
3	**Social and economic assessment of tourism along the Ningaloo Coast: a dynamic modelling approach**		
	Project leader: *Prof. David Wood (Curtin)*		
	3.1	Continuation of long term survey of visitation (Jan 09)	*David Wood, Tod Jones (Curtin)*
	3.2	Environmental load survey of accommodation providers (Jul 08)	*Michael Hughes, Tod Jones (Curtin)* *Karin Schianetz (UQ)*
	3.3	Resident survey of social impacts of tourism (Jul 08)	*Marg Deery (VU)* *Liz Fredline (Griffith)* *David Wood, Tod Jones (Curtin)*
	3.4	Assessment of economic values of tourism (Jul 08)	*Larry Dwyer, Ray Spurr (UNSW)* *David Wood, Tod Jones (Curtin)*
	3.5	Ningaloo destination model for scenario evaluation and collaborative planning (Jul 09)	*Tod Jones (Curtin)* *Karen Schianetz (UQ)*
4	**Estimation and integration of socioeconomic values of human use of Ningaloo in the MSE model structure**		
	Project leader: *Assoc Prof. Michael Burton (UWA) / Dr Atakelty Hailu (UWA)*		
	4.1	Survey of recreational fishing choices	*Michael Burton*
	4.2	Random utility models for recreational fishing choices	*Michael Burton*
	4.3	Random utility models for other non-recreational tourist activity choices	*Michael Burton*
5	**Management strategy evaluation for the Ningaloo region**		
	Project leader: *Bill DelaMare, CSIRO*		
	5.1	Linkage and socioeconomic integration for NMP	*Bill DelaMare (CSIRO)*
	5.2	Qualitative modelling for sustainable tourism development	*Jeff Dambacher (CSIRO)*
	5.3	Integrated software for multiple use management strategy evaluation	*Beth Fulton (CSIRO)*
	5.4	NREP Client Outreach	*Geoff Syme (CSIRO)*

For further information or to download a copy of the progress report,
visit the Ningaloo Research Website:

www.ningaloo.org.au