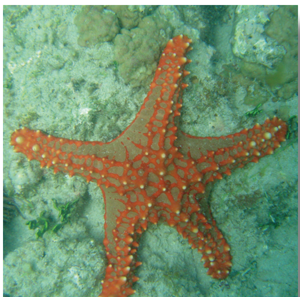
Ningaloo into the future: integrating science into management

3rd annual Ningaloo Research Symposium



ABSTRACTS

26 – 27 May 2009

Novotel Ningaloo Resort

Exmouth, Western Australia

Department of Environment and Conservation
Our environment, our future

western australian marine science institution

National Research FLAGSHIPS
Wealth from Oceans
CSIRO

Murdoch University

Third Annual
Ningaloo Research Symposium

Ningaloo into the Future: Integrating Science into Management

26 and 27 May 2009

Novotel Ningaloo Resort
Exmouth, Western Australia

Sponsored by:

Department of Environment and Conservation,
Western Australia

CSIRO Wealth from Oceans National Research Flagship's
Ningaloo Collaboration Cluster

Western Australian Marine Science Institution

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INTRODUCTION

The Ningaloo Marine Park (NMP) is one of Australia's most spectacular marine environments and is recognised as a global biodiversity hot spot. From the ocean, gulf and reef up into the nearby ranges the Ningaloo and Exmouth region is the centre of a broad range of biological activity, but is equally the focus of a range of human activities. Balancing conservation, use and management of this unique marine ecosystem with sustainable development of the region is a major challenge.

The Ningaloo Research Program (NRP) was initiated in 2005 with funding of $5 million from the Western Australian Government to meet this challenge, recognising that extensive research will contribute to our understanding of the NMP and adjacent regions, its biodiversity and ecosystem processes and how these interact with human and natural pressures.

The research program, developed in consultation with the scientific community and resource managers, is based on the research and monitoring needs identified in the 2005 NMP Management Plan. It aims to provide a better understanding of the natural values within the marine park and how best to manage them effectively. The program demonstrates a truly collaborative approach to address a broad range of social and ecological topics and includes co-investment from government departments, national research organisations and universities.

The NRP is primarily being undertaken through Node 3 of the Western Australian Marine Science Institution (WAMSI), led by the WA Department of Environment and Conservation (DEC) and through the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster (administered by Murdoch University) along with additional projects funded by Western Australian universities, industry and the Australian Institute of Marine Science. Altogether, it represents a collective investment of more than $30 million over five years.

In 2007 the Ningaloo Research Coordinating Committee (NRCC) was formed to assist in integrating the research findings and information from the program's vast array of work. The NRCC works to ensure that resource investment in research is maximised through collaboration, shared information and a joint approach to science communication and integration. One of the main avenues for this integration has been through forums such as the annual Ningaloo Research Symposium. These symposia provide an opportunity to bring researchers and stakeholders together to share recent findings and make the most of the information being produced.

The NRP has been underway for three years and is producing a vast quantity of quality science directed at answering management questions and filling in knowledge gaps to support sound management decisions. As projects begin to reach completion it is critical to now focus on the integration of this information into the decision making processes that guide and support management of the NMP and surrounding region.

Thus, the focus of the 3rd Annual Ningaloo Research Symposium is on this integration, in particular exploring:

- The type of information used in regional planning including marine protected area management plans;
- how managers engage with scientists and the information they provide; and
- how scientists can direct their research and present their findings so that they are incorporated into management decision making processes.

The symposium will be opened by the WA Chief Scientist, Professor Lyn Beazley, and will include a keynote presentation by Professor Bruce Thom providing a national perspective on coastal management and regional planning. This will be followed by a range of presentations from managers and scientists with a focus on the integration of science into marine protected area management.

By holding the symposium in the Ningaloo region, we hope to reach a broader audience of local community and regional stakeholders so we can work towards a shared understanding and appreciation of the values in Ningaloo Marine Park and the best ways to preserve them.

Thank you for your participation. We are confident you will find the symposium a rewarding and enjoyable experience.

Dr Chris Simpson, Program Leader, Marine Science Program, WAMSI Node 3 Leader; **Dr Kelly Waples**, Department of Environment and Conservation, WAMSI: Node 3

Prof. Neil Loneragan, Leader, the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster, Chair in Fisheries Science Murdoch University; **Irene Abraham,** Executive Officer Ningaloo Collaboration Cluster, Murdoch University

Dr Bill de la Mare, Theme Leader, The Marine Nation, CSIRO Wealth from Oceans National Research Flagship; **Wendy Steele**, CSIRO Wealth from Oceans National Research Flagship; **Edwina Hollander** CSIRO Marine and Atmospheric Research

PROGRAM

Third Annual Ningaloo Symposium
26 and 27 May 2009
Novotel Ningaloo Resort, Exmouth, Western Australia

Day 1 Tuesday 26 May		
Time	**Presentation**	**Speaker**
8:40	Registration and morning coffee and tea	
9:00	Introduction and welcome	Neil Loneragan *(Leader, the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster / Chair in Fisheries Science Murdoch University)*
9:10	Welcome to Country	Ann Preest Director *(Chairperson North West Cape Exmouth Aboriginal Corporation)*
9:20	Opening	Professor Lyn Beazley *(WA Chief Scientist)*
	Key Note Address A national perspective on coastal management and coastal landuse planning	Professor Bruce Thom *(President of the Australian Coastal Society and a member of the Wentworth Group of Concerned Scientists)*
Session 1 – Chair: Neil Loneragan, *Leader, Ningaloo Collaboration Cluster / Murdoch University*		
10:00	**Overview** Integrating science understanding into conservation and management of marine areas.	Kelly Waples *(Dept of Environment and Conservation WA)/* Russ Babcock *(CSIRO)*
10:30	Fish surveys across Ningaloo and the effectiveness of the current zoning of the marine park	Russ Babcock *(CSIRO Wealth from Oceans National Research Flagship)*
10:50	High resolution mapping of reef utilisation by humans in the Ningaloo Marine Park	Lynnath Beckley *(Murdoch University)*
11:10	***Morning Tea***	
Session 2 – Chair: Kelly Waples, *Dept of Environment and Conservation WA*		
11:30	Toward a global biodiversity baseline for coral reefs	Julian Caley *(Australian Institute of Marine Science)*
11:50	Current status of the invertebrate fauna targeted by fishers and the possible outcomes of different management alternatives	Martial Depsczynski *(Australian Institute of Marine Science)*
12:10	Are there indirect effects of fishing on the Ningaloo Ecosystem?	Mat Vanderklift *(CSIRO Wealth from Oceans National Research Flagship)*
12:30	Intertidal Invertebrates	Mike Johnson *(University of Western Australia)*
12:50	Biodiversity studies in the Ningaloo Reef lagoon	Mike Van Keulen *(Murdoch University)*
13:10	***Lunch***	

Session 3 – Chair: Bill de la Mare, *Theme Leader, CSIRO Wealth from Oceans National Research Flagship*		
14:00	**Overview** Sustainable Fisheries Management	Mervi Kangas and Jenny Shaw *(Department of Fisheries WA)*
14:30	Evaluating Management Strategies for Line fishing in the Ningaloo Marine Park	Rich Little *(CSIRO Wealth from Oceans National Research Flagship)*
14:50	Gascoyne Scalefish Sustainability	Ross Marriott (*Department of Fisheries WA*)
15:10	Research and management of the Exmouth prawn fishery	Mervi Kangas and Errol Sporer (*Department of Fisheries WA*)
15:30	***Afternoon Tea***	

Session 4 – Chair: Russ Babcock, *CSIRO Wealth from Oceans National Research Flagship*		
15:50	Magnitude and patterns of herbivory in Ningaloo Reef	Adriana Verges *(Edith Cowan University)*
16:10	Testing zone adequacy: Movement and habitat utilization of fishes in Ningaloo Marine Park	Richard Pillans *(CSIRO Wealth from Oceans National Research Flagship)*
16:30	Loggerhead turtle nest predator dynamics on a mainland nesting beach in Cape Range National Park ***Invited Presentation from Ningaloo Student Research Day***	Sabrina Trocini *(Murdoch University)*
16:50	Summary and Discussion	Chris Simpson *(WAMSI Node 3 Leader, Program Leader, Marine Science Program, DEC)*
17:30	Close of Day 1	

Day 2 Wednesday 27 May

Session 5 – Chair: Geoff Syme, *CSIRO Wealth from Oceans National Research Flagship*		
Time	**Presentation**	**Speaker**
8:45	**Overview** Science in sustainable use of natural resources/ Informing natural resource management	Beth Fulton *(CSIRO)* /Peter Rogers *(Western Australian Marine Science Institution)*
9:15	Understanding Complex Systems Through Use of Simple (Qualitative) Models	Jeff Dambacher *(CSIRO Wealth from Oceans National Research Flagship)*
9:35	The Resilience of Tourism to the Ningaloo Coast: the Ningaloo Destination Modelling Process and Model Use	Tod Jones *(Curtin University)*
9:55	Modelling Recreational Site Choice for Ningaloo	Atakelty Hailu *(University of Western Australia)*
10:15	Testing system understanding across different complex management problems: an introduction	Fabio Boschetti *(CSIRO Wealth from Oceans National Research Flagship)*
10:35	***Morning Tea***	

Session 6 – Chair: Mike van Kuelen, *Murdoch University*		
10:55	Ningaloo Deeper Water Biodiversity: a WAMSI collaboration in progress	Andrew Heyward *(Australian Institute of Marine Science)*
11:15	Mapping the marine benthic habitats of Ningaloo Reef lagoon	Halina Kobryn *(Murdoch University)*
11:35	Geomophology and Reef Growth History	Lindsay Collins *(Curtin University)*
11:55	Characterisation and modelling of oceanographic processes in Ningaloo Reef	Chari Pattiaratchi *(University of Western Australia*)
12:15	Biological oceanography	Anya Waite *(University of Western Australia)*
12:35	Long term trends in the Leeuwin Current and implications for marine ecosystems	Ming Feng *(CSIRO Wealth from Oceans National Research Flagship)*
12:55	***Lunch***	
Session 7 – Chair: Jeff Dambacher, *CSIRO Wealth from Oceans National Research Flagship*		
13:45	**Overview** Science and management in land use and planning	David Wood *(Curtin University)*
14:15	Regional management of the Ningaloo Marine Park	Roland Mau *(Department of Environment and Conservation WA)*
14:25	Establishing a long term monitoring programme for key ecological and social assets in WA	Kim Friedman *(Department of Environment and Conservation WA)*
14:45	Knowledge and role networks-enhancing the effectiveness of models in assisting decision making	Peta Dzidic *(CSIRO Wealth from Oceans National Research Flagship)*
15:05	Translating research into practice- building adaptive institutions	Kelly Chapman *(Edith Cowan University)*
15:25	***Afternoon Tea***	
Session 8 – Chair: David Wood, *Curtin University*		
15:50	Whaleshark biology and conservation at Ningaloo	Brad Norman *(Ecoceans)*
16:10	Visualisation of complex environmental data sets	Stuart Minchin *(CSIRO Land & Water)*
16:30	Summary and Discussion	Bill de la Mare (*Theme Leader, The Marine Nation, CSIRO Wealth from Oceans National Research Flagship)*
17:10	Close and refreshments	
18:00	**Workshop** Simulating Ningaloo – how to play the game	Beth Fulton and Fabio Boschetti *(CSIRO Wealth from Oceans National Research Flagship, Marine & Atmospheric Research)*

Symposium Workshop:
Simulating Ningaloo – How to play the game

Beth Fulton and Fabio Boschetti (CSIRO Wealth from Oceans National Research Flagship, Marine & Atmospheric Research)

Novotel Ningaloo Resort, 6:00pm Wednesday 27 May 2009

The workshop will provide the opportunity to delve further into the Management Strategy Evaluation (MSE) used at Ningaloo and is intended for participants from the science and local community, as well as managers and other stakeholders.

Summary:
From the ocean, gulf and reef up into the nearby ranges, the Ningaloo and Exmouth region is the centre of a broad range of biological activity, but is equally the focus of a range of human activities.

Everyone with an interest in Ningaloo; science, business, recreation or lifestyle has their own objectives for the area and ideas about its future.

Scientists want to "simulate" these ideas with a variety of management and development plans for the region.

By using a specially designed computer model of the Ningaloo Marine Park, the outcomes take into account its physical structure, the marine ecosystem, human use and economics.

This workshop will explain how the modelling has worked to date, the ideas that have already been discussed and answer any further questions. Discussion of new ideas is welcomed to help broaden the possible options that can be considered with this technology. It is important that a broad a range of people are involved with providing comprehensive input to the process, as it is not about finding "the single best solution" but highlighting where tradeoffs and compromises need to be made for the most favourable outcome for all involved.

EXTENDED ABSTRACTS

FOR KEYNOTE AND

OVERVIEW PRESENTATIONS

Key Note Address

A National Perspective on Coastal Management and Land Use Planning

Professor Bruce Thom

President of the Australian Coastal Society

There have been many attempts to develop a national perspective on coastal management in Australia. It has been a struggle. Federal government inquiries since 1980 have yielded recommendations on the need for all levels of government to work more closely in the coastal domain. Even the CSIRO has had difficulties in finding a place for coastal science that would provide a knowledge base for improved management and planning of the region of Australia occupied by 85% of its population together with many of its powerhouse economic systems and its cultural mystic.

There are a number of factors that explain this rather strange view of a national asset such as our coastal resources. In this connection we differ somewhat from other large federated nations. In Australia, a range of institutional barriers hinder efforts to integrate or even achieve a reasonable level of cooperation in progressing coastal science in ways that would impact on national policy and on arrangements between governments. Constitutional and bureaucratic impediments exist that limit how the states work with the Commonwealth in areas such as land use planning.

Recent initiatives by the present Australian Government have opened up new avenues for what could be a new era of cooperation between all levels of government in coastal planning and management. A new driver has emerged: the imperative to consider how best to adapt to the potential impacts of climate change in coastal areas. The current House of Representatives Inquiry is fleshing out many facets of the issues related to climate change and governance. In addition the Department of Climate Change is very active in assessing how impacts may be best understood and managed. State and local governments are increasingly looking for better ways to manage risks to assets and environmental values that are vulnerable to climate change. These initiatives represent a good opportunity to elaborate and test new models for managing science outputs and for improved institutional arrangements in coastal management for the benefit of the nation.

Overview

Integrating science into management to support marine conservation: a management perspective

Kelly Waples and Chris Simpson

Marine Science Program, Department of Environment and Conservation, Kensington, WA

Two major objectives of government conservation agencies are the conservation of biodiversity and the maintenance of ecosystem life-support processes through sustainable management of human activities and resource use. These aims require a good understanding of the characteristics of the system, the processes that support them and their responses to existing and potential pressures and threats.

Science has a critical role to play in providing information that describes the natural environment (i.e. inventory and baseline knowledge) and developing understanding of natural and anthropogenic changes to the system and the implications of these changes over the long term (i.e. process and prediction). This knowledge is critical to understanding the key ecological and social assets of the system, the processes that sustain them and the potential impacts that may be caused by pressures upon them. The interaction between science and management is then necessary to relay the information gained through scientific investigation into the development of strategic (i.e. proactive) conservation and management programs. The transfer and uptake of scientific knowledge to inform management[1] is the subject of this paper, particularly in relation to the management of Ningaloo Marine Park (NMP).

The transfer and uptake of scientific knowledge, between scientists and managers, happens rapidly and easily when an existing issue or problem is contentious and/or has a high public profile, for whatever reason. In the instance where strong economic or social/political imperatives are at work there is usually good communication between policy makers, managers and scientists, leading to rapid assessment, provision of additional necessary information and consequent decision-making and action.

A recent example of the efficiency of 'reactive' knowledge transfer and uptake is the management response to the commercial marine nature-based tourism industry interacting with the Monkey Mia dolphins in Shark Bay Marine Park, Western Australia. The Monkey Mia dolphins are an iconic natural feature of the marine park, are of international scientific interest, generate intense public interest in Australia and overseas and are, as a result, a politically sensitive issue in Western Australia. Following concerns of potential impacts on the wild dolphin population due to increased pressure from commercial tour interactions, a study was initiated to address specific management questions in conjunction with the assessment of a long-term dataset on dolphin population dynamics. Information was presented to policy makers confirming significant declines in the local dolphin population and in their reproductive output and indicating that these impacts were most likely related to the level of interaction with tour boats (Bejder et al. 2006). Subsequently, the Minister for the Environment decided to reduce the number of permitted tour boats to a previous 'no impact' level.

While there are numerous similar examples of the rapid 'reactive' transfer of science into management action to address existing problems, it is more difficult to find examples of 'proactive' transfer and uptake to prevent problems that will/may arise in the future. In the absence of clear economic and/or social 'drivers', the flow of information between scientists and managers is often slow and uptake is limited. This often leads to, at best, limited recognition by policy makers and managers of the value of science and, at worst, accusations of irrelevance and of wasted resources. Passive interest or

[1] 'Management' is used here in the generic sense and refers to policy, planning and operational management

disengagement by scientists in directing their research findings to improve resource management is often the predictable response to this lack of appreciation of the value of strategic (i.e. proactive) science. It is in this proactive management arena that knowledge transfer and uptake often stagnates.

Marine Conservation: Protected Area Planning and Management

Marine biodiversity conservation in Western Australia is primarily achieved through the gazettal of representative marine ecosystems in a statewide system of marine protected areas (MPA). MPAs in Western Australia are multiple-use and include 'no take' areas as well as permitting recreational and commercial activities in appropriate zones. Marine park planning and management is one such area where management seeks to establish strategic plans to proactively manage the ecological[2] and social[3] assets within MPAs such as NMP. Marine park management plans identify and assess these assets along with their current status, information gaps and potential threats or pressures upon them. Management goals (i.e. objectives and targets for each asset) are established and are achieved through the application of appropriate management strategies. A risk assessment approach is applied that assesses the relative conservation significance (or value) of the ecological assets, the threats and level of current knowledge (in relation to research and monitoring strategies) to determine management objectives, the strategies to achieve them and their relative priority (Simpson et al. 2002, CALM 2005).

In WA, MPA management plans employ seven generic management strategies to varying degrees to assist in achieving management targets. These are:

- **Management frameworks** – including government and institutional policies, the statutory elements of legislation, regulations and management plans along with the infrastructure, resources and personnel to implement them;
- **Education** – to develop an understanding in the community and by visitors of the natural values in the park, impacts caused by human activities and the reasons for their regulation;
- **Patrol and enforcement** - management of human activities within an MPA relies on compliance with regulations. Surveillance is necessary to determine the level of compliance and the necessity to intervene where regulations are not being followed;
- **Management intervention** - can be reactive (restoration or recovery actions where human activity has impacted a natural asset) or proactive (actions that prevent impacts before they cause damage).
- **Public participation** –effective management of an MPA requires community support through a shared understanding of the natural values and how regulatory and other measures will lead to their protection. This is most effectively achieved through public participation in management activities;
- **Research** – provides the critical information that improves our understanding of the structure and function of ecosystems, how we interact with the environment and what kind of impact these interactions may cause; and
- **Monitoring** (and evaluation) – measures trends, usually of marine resource condition, pressures, and the effectiveness of management responses.

In addressing any single asset within a marine park, a balance is sought between these strategies that depends on the characteristics of the asset and circumstances surrounding it. For example, if the major threat to coral communities is damage by divers and boat anchors then the conservation of coral communities may rely primarily on a combination of implementing a zoning scheme that limits these activities in part of the MPA, providing public education to limit widespread damage to coral from swimming, diving and boating, establishing dive trails and public moorings in areas of particularly high use and monitoring coral condition to assess the effectiveness of this combination of management strategies. Similarly, the long-term

[2] Ecological assets are the intrinsic physical, chemical, geological and biological characteristics (i.e. structures and functions) of an area and include marine flora and fauna and the geological and physical components of the ecosystem that support them.

[3] Social assets are the major cultural, aesthetic, recreational and economic uses of the area, including both passive (e.g. wilderness, seascape) and active (e.g. fishing, tourism) uses.

conservation of deep water benthic communities that, for example, are under no major current pressure, may rely initially on research to fill in information gaps about structure and function and identifying relevant monitoring indicators, public education on the ecological importance of these areas to build public support for protection measures, adjustment of zoning schemes to provide the necessary legal protection by excluding potential harmful activities, patrol and enforcement programs to ensure compliance and monitoring and evaluation programs to assess the effectiveness of these strategies. See Table 1 for further examples of the relative emphasis of the generic strategies in relation to specific management issues.

Natural resource managers rely on this process in the development of management plans and in determining the most effective combination of strategies. Ideally then, this becomes an iterative process through the adaptive management cycle where management strategies can be evaluated and refined over time with the appropriate feedback of information (Figure 1).

Process for Knowledge Transfer
Knowledge transfer refers to the movement of information between researchers, managers and policy makers ultimately leading to the uptake of that information into management activities and practices. Traditionally, knowledge is generated by the scientists through investigative research. This information is distilled into reports and publications and is communicated through the scientific literature, symposiums, conferences and seminars or direct interaction between individuals. Ideally, management agencies then use the information in the development of management plans, establishment of monitoring programs and policy

Knowledge transfer can occur when scientists act as advocates to ensure research findings and recommendations reach a suitable audience. With this scenario, scientists push for particular decisions/outcomes. Knowledge transfer can also occur when there is an intermediary who acquires and interprets scientific findings and applies them to relevant management issues. The latter can occur without scientists promoting a particular course of action and is often one role of scientists within government agencies (e.g. the Marine Science Program within the DEC)

The uptake of knowledge then occurs when this information is used to inform policy and decision making processes. Often it is this final stage that is limited or even blocked. As noted above, this process occurs smoothly and rapidly when there are political or social imperatives at work, that is, when there is an incentive for rapid decision making. In this instance, managers seek out scientists with specialist knowledge, resources are made available for specific directed research and findings are translated into recommendations leading to changes in policy, regulation or management action.

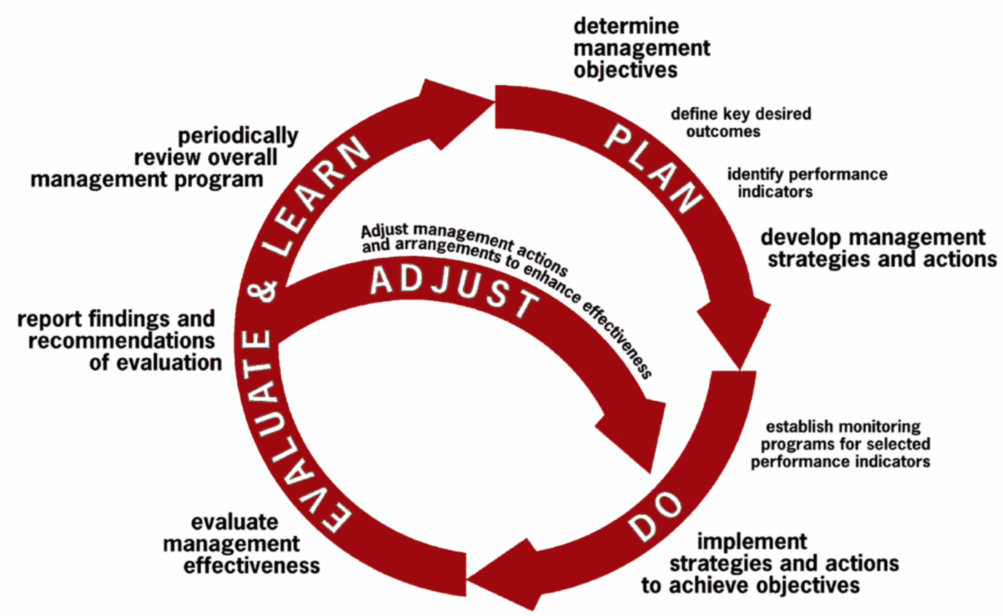

Figure 1. The adaptive management cycle (Jones 2005).

However, as described above, when there are no specific imperatives or ‘issues’ at stake, knowledge transfer can be slow and uptake limited. There are a variety of reasons that have been identified in previous reviews that block knowledge transfer (e.g. Briggs 2006, Woodley 2006, Roux et al.1969) including differences in culture, reward systems and timeframes. When there is no high priority imperative though, there can often be disengagement between scientists and the application of their research and between managers/policy makers seeking and adopting research findings.

Ideally, knowledge transfer and uptake should be part of the adaptive management cycle leading to the ongoing evaluation and adjustment of management strategies (Figure 1, Jones 2005). In this regard knowledge transfer is an ongoing process requiring a dialogue between scientists and managers to reach a shared understanding of the issue, potential strategies, effectiveness of those strategies and adjustments to improve them (Simpson et al. 2008).

In developed countries like Australia, the establishment and management of MPAs is primarily a proactive strategy to conserve marine biodiversity in relatively undisturbed ecosystems rather than as a strategy to remediate degraded areas. As a result, while it is widely acknowledged marine park management plans and subsequent management activities are critical for the long term sustainability of marine resources, most MPA management issues do not have a high public profile or are politically contentious. As such, the political/social concerns that provide the institutional incentives for rapid knowledge uptake and action are often absent. Thus the related research activities outlined in these plans often fall into the category of ‘proactive’ knowledge transfer and uptake outlined above.

Management of the NMP is just such an example. It is generally accepted that, from a global perspective, NMP is a healthy and viable marine park with relatively limited threats or pressures to its biodiversity, thus there are few immediate concerns or problems to solve. However, the long-term management and sustainability of the marine park still relies on scientific information being sought and incorporated into management in a strategic and proactive manner to address potential problems before they arise. The current NMP management plan, released in 2005, identifies the ecological and social assets of the marine park along with the management strategies required to meet management objectives. The Ningaloo Research Program (NRP) was established to meet many of the research and monitoring needs outlined in the plan as well as assess the overall effectiveness of management. It is critical for the success of the NRP that the information gained through the research meets management needs and that the outcomes are duly recognised and acted upon by managers and policy makers.

Establishing a Knowledge Transfer Framework

Our goal is to create a logical pathway or framework for both scientists and managers that will bring them to a shared understanding of management opportunities in marine conservation so that relevant information is recognized and used both in ongoing management activities and to shape research design. The framework use the research projects in the NRP as examples to outline how information on particular themes or topics can be applied through the seven generic management strategies.

This process was initiated through the identification of research and monitoring needs in the NMP Marine Park Management Plan which framed the NRP. Subsequently, management questions for each of the projects in the NRP were developed by the DEC, provided to the relevant project leaders and discussed in light of project proposals and milestone reports to ensure that they would be addressed through research design and reporting schemes. For example, the following questions were provided for the research on deepwater habitats and communities conducted by AIMS:

- What are the major benthic/demersal communities in the deeper waters of NMP and what is their abundance and distribution?;
- Are there any correlations between habitat or physical characteristics and this distribution?;
- Is the current sanctuary zone scheme providing representative and adequate protection of these communities?; and
- Which functional groups/species can be used as indicators of community condition and what spatial and temporal scale should be used to monitor them?

The next step is to construct a matrix into which research topics and themes are described in relation to the types of information they produce and how this may be applied by managers and decision makers. As noted above, managers have a variety of strategies to consider when addressing management needs. Effective management relies on finding the appropriate balance of these strategies to address specific issues and it is in this regard that science through research can assist.

For the management objectives of each ecological and social asset in the marine park, the framework will include the following:

- Specific management questions;
- how the information might be applied through the seven generic management strategies;
- the relevant users of the information who will apply it to management actions; and
- the best format for knowledge transfer that will be understandable and useful to those users (ie. report with recommendations, map, model outputs).

Ideally, this framework will be of use to both scientists and managers so that they will have a better understanding of the tools used by each, the types of questions that can be asked and the research outcomes that can be directed towards management action. By ensuring that both scientists and managers have a general understanding of how specific science information is incorporated into management actions inside this framework we hope to assist in the application of science into the marine park management model. Table 2 contains several examples derived from projects within the Ningaloo Research Program. This table and the information it contains should be considered as a working document, one that provides guidance and ideas on the application of science. However, it is not an exhaustive list and we expect that both scientists and managers would have further input and suggestions on additional applications, users and relevant formats.

Enhancing knowledge uptake

Along with assisting both scientists and managers to consider the specific application of science to management needs, there are several other elements required to enhance knowledge uptake over the longer term:

(1) **Data Management**. Long-term data storage and custodianship is critical to ensure that information is available and accessible into the future. This will reduce the unnecessary repetition of research. This is particularly important for long term conservation as research underway today might include information or datasets that become important in the future as situations change (e.g. in relation to the impacts of climate change).

(2) **Communication** is essential to ensure that there is a common understanding of marine resources and relevant research and that the outcomes and relevant information is provided in a digestible format to those who will use it. This process should involve some interaction between scientists and managers to define questions of interest and will also include standard science communication such as publication of papers and presentations at conferences and seminars. However, it is important to consider the best means of getting messages across to the relevant audience. This may also be facilitated by personal communications rather than relying solely on scientific publications.

(3) **Modeling Tools**. There are a variety of tools available to management agencies to assist them in interpreting and applying science to management. The Management Strategy Evaluation (MSE) is an example of a useful modeling tool designed to test out various scenarios and the success or otherwise of relevant management strategies. However, for these models and their outputs to make sense to managers and policy makers, there is a need for an operational interface and a level of interpretation that will engage both the scientist to gather and input the information and resource managers to then use the tool for strategic and proactive management.

(4) **Intermediary/interpreter**. As noted at the outset, when there are political or social imperatives at stake this process will happen. However, when there are no such incentives, there will need to be an advocate pulling the

parties together, harnessing scientific energy and information and engaging managers and policy makers to proactively address specific marine conservation and marine park management needs. The Marine Science Program (MSP) within the DEC has just such a role and is seeking to promote this strategy internally as well as within other similar government agencies.

The key elements on which the MSP will focus to fulfill this role include:

- Setting strategic direction for marine research through the development of strategic research plans and clearly defined management questions;
- developing clear and open communication with both internal and external scientists through direct contact, collaboration, symposia and publications;
- ensuring long term data management for internal DEC datasets as well as encouraging similar meta data-basing, long term data storage and custodianship for external research;
- actively working with external scientists and DEC marine managers to clearly identify immediate and potential applications of research outputs; and
- adopting and promoting tools such as the MSE to review and assess current management strategies and their long term suitability.

The ultimate end point should be a shared, mutually agreed conclusion such as a policy document, management guideline or a planning guideline in which all parties have participated. Such documents will have added value as they will be specific, providing on the ground and operational detail with the sound backing of the appropriate science. By recognizing the importance of each step in the process from knowledge generation to uptake and working together we hope that the NRP will stand as a prime example of the value of science in marine natural resource management.

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Table 1: Examples of the balance of generic management strategies employed to address particular issues. Examples of specific actions are outlined in the footnotes.

ASSET	PRESSURE	GENERIC MANAGEMENT STRATEGY						
		Management Frameworks	**Education**	**Surveillance & Enforcement**	**Management Intervention**	**Public Participation**	**Research**	**Monitoring**
Coral communities	Localised anchor/boat damage by commercial coral viewing operations	√√√ [1]	√	√	√√√ [2]	√	[3]	√√ [4]
Coral communities	Widespread low level diver/anchor damage by recreational divers/boaters	√	√√√ [5]	√	√√√ [6]	√	[3]	√
Spangled emperor	Intense harvesting by fishers	√√√ [7]	√√√ [5]	√√√ [8]		√√ [9]	√√ [10]	√√ [11]
Rock lobster (scenario 1)	Over-exploitation by fishers	√√√ [7]	√√√ [5]	√√√ [8]	√√√ [12]	√√√ [9]	√√√ [10]	√√√ [11]
Rock Lobster (scenario 2)	Over-exploitation by fishers	√√√ [13]	√	√√√ [8]		√		√√ [11]
Deepwater benthic communities	No significant pressure	√	√				√√√ [14]	√√ [11]

Key: √√√ = high management response; √√ = moderate management response; √ = low management response

[1] Apply appropriate statutory license conditions (e.g. designated viewing areas, 'anchoring' and compliance monitoring conditions, etc); Operator codes of conduct etc
[2] Install public moorings at viewing sites; Private moorings at boat mooring locations; etc
[3] Not needed as cause-effect pathway is understood; assume reef wide habitat and human use information is available; etc
[4] Ensure annual compliance monitoring by operators of designated area prior to license renewal; Undertake agency monitoring every three years; Lease renewal based on condition of asset
[5] Undertake intensive public education programs
[6] Install of public moorings at popular dive sites
[7] Establish adequate 'no take areas' (NTAs) over representative habitat; adjust fishing regulations (e.g. species, bag, size and possession limits); etc
[8] Ensure compliance programs are effective (re: NTAs and fishing regulations)
[9] Promote voluntary reporting of catch and effort by public; participation in community monitoring programs; etc
[10] Locate spawning sites for inclusion in NTAs; assess ecosystem impacts; etc
[11] Monitor resource condition against management targets to assess effectiveness of management strategies
[12] Enhance adult population via translocation; etc
[13] Prohibit the take of lobsters
[14] Determine distribution and abundance; identify environmental correlates, assess representativeness in NTAs and identify monitoring indicators; etc

Table 2. Examples of some of the potential management implications/responses to research findings from a selection of projects currently underway in Ningaloo Marine Park.

RESEARCH TOPIC	MANAGEMENT QUESTIONS (examples only)	MANAGEMENT IMPLICATIONS/RESPONSES (examples only)							USER/S	FORMAT
		Management Frameworks	Education	Surveillance & Enforcement	Management Intervention	Public Participation	Research	Monitoring		
Patterns of deep- water biodiversity	• What are the major benthic communities in deep-water and how are they distributed? • Do the sanctuary zones provide adequate and representative cover of these communities?	Will allow an assessment of sanctuary zone scheme to ensure appropriate representation of deep-water habitats.	Will assist the development of public education programs to increase community understanding of the unique values of NMP deep-water biodiversity.	Will inform the design of deep-water compliance programs by identifying areas of particular biodiversity significance.			Will significantly improve the knowledge base of NMP's biodiversity and its conservation significance.	Will provide the knowledge base (e.g. condition surrogates) to design an appropriate monitoring program for the deep-water biodiversity of NMP.	DEC MPA planners, field managers and scientists, fisheries managers.	GIS referenced map; report and figures; in policy/ planning/ management guidelines.
Patterns of reef use	• What, where, when and how are people using NMP? • What indicators should be used to monitor human use in NMP?	Will assist planning and management of commercial and recreational use in NMP.	Will assist the design of education programs by identifying the aspirations and behaviours of park users.	Will provide information to design effective surveillance and enforcement programs.	Will identify visitor infrastructure needs (e.g. upgrade of access points/relevant facilities).	Will assist the design of community-based social monitoring programs.	Will significantly improve the knowledge base of the patterns and trends of human use in NMP.	Will assist the design of ecological and social monitoring programs in NP (e.g. indicators, spatial and temporal scales, existing threats, emerging pressures etc).	DEC MPA planners, recreation and tourism planners, field managers and scientists, fisheries managers.	GIS referenced maps; report and figures; in policy/ planning/ management guidelines.
Lagoon fish community structure	• What is the diversity, abundance and size composition of key fish species in representative habitats? • How does the above compare between historic unexploited and current exploited areas? • Is the sanctuary zone scheme appropriate/effective? • What indicator species should be monitored and over what temporal/spatial scales?	Will allow an assessment of the representativeness and adequacy of the sanctuary zone scheme in regard to the lagoon fish communities; will provide information on the effectiveness of current recreational fishing regulations in NMP.	Will assist the development of public education programs to increase community understanding of the functional role and value of sanctuary zones.	May provide information on the effectiveness of historical and current surveillance and enforcement programs.		Will provide critical information for public discussion on the effectiveness of current recreational fishing regulations in NMP.	Will significantly improve the knowledge base of lagoon fish ecology.	Will provide initial baseline datasets and the knowledge base to design appropriate monitoring programs (e.g. indicator species, spatial and temporal scales etc).	DEC MPA planners, field managers and scientists, fisheries managers.	Report and figures; in policy/ planning/ management guidelines.
Oceanograph y of Ningaloo Reef	• What are the patterns of water circulation and transport in NMP and what are the major 'drivers' of these patterns? • How does water movement influence the distribution of biodiversity (e.g. connectivity, management units)? • Under what conditions and where in lagoons are current speeds a public safety hazard?	Assist in marine recreational and tourism planning by identifying areas of public risk; Will assist in understanding spatial scale of functional management units within NMP.			Will assist in emergency response (e.g. oil spill, search and rescue etc); will assist the design of public mooring plans etc		Will significantly improve the knowledge base of water circulation and transport in NMP; Will assist studies on connectivity, nutrient and carbon flux etc.	Will assist the design of monitoring programs (e.g. location of reference sites) by identifying areas vulnerable to potential climate change impacts (e.g. coral bleaching).	DEC MPA planners, recreation and tourism planners, field managers and scientists, fisheries managers.	GIS referenced map; model outputs under the range of forcing factors; in policy/ planning/ management guidelines.

Overview

Integrating science into management strategies and actions to support marine conservation: the scientist's perspective

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The first imperative of a scientist is the pursuit of knowledge and discovery; this is what really motivates most scientists. Secondarily scientists have to make their science relevant to society, in order to survive academically. Environmental scientists have a further responsibility to make their science relevant to positive environmental outcomes.

The Ningaloo Research Program (NRP) provided a framework that enabled discovery by ensuring that science was relevant to positive conservation outcomes. It included objectives, based on Key Performance Indicators aimed at providing both primary (inventory) and secondary (process-based or conceptual) information. Both types of information are necessary for ongoing adaptive natural resource management such as required in multiple-use marine parks. For example, surveys of the distribution and diversity of sharks and rays as well as for key fish species in the park was a key component of several projects in WAMSI Node 3.2. While park zoning decisions had to be made prior to these large scale surveys, it was important to establish whether or not the re-zoning had been successful in capturing the full range of biodiversity. This was not simply to vindicate decisions already made, but to inform the next review of the zoning in the park. As it turns out, the patterns revealed by the surveys do show that the re-zoning does include a more comprehensive and representative set of fish assemblages than the previous zoning.

In order to achieve protection of targeted species of fish or invertebrates, or those vulnerable as by-catch, zoning areas within marine parks as "no-take", presumes that population density and biomass for targeted species will increase, as well as restoring more natural population structures. This presumption is generally supported by results from around the world, but the international literature also makes it clear that predicting which species will respond best to this type of management, the degree to which populations will recover from fishing pressure, and how long it will take for populations to respond are difficult to predict in detail. Responses may be influenced by each species' biology, local fishing regimes, a species' mobility, the size and shape of no-take areas, as well as their exact location of areas in relation to key habitat features such as spawning or nursery areas.

In order to fine-tune zoning provisions in Ningaloo Marine Park and implement any necessary adaptive management actions, an assessment of the effectiveness of no-take zones must be undertaken. This has been done throughout the park with the result that several of the key targeted species are shown to be significantly protected within the no-take areas. These surveys also provided baseline data and methodology for ongoing adaptive management, although the exact details of how tis information will be used and what form any future monitoring program will take remain to be determined. For some species the data suggest that the shape and size of previous zones, which stopped at the reef crest, were not adequate to protect some species, especially those that are found mainly outside the lagoon.

A tagging program has been undertaken using acoustically tagged fish and an array of listening stations in order to better assess how zone shape and size interact with species' biology to influence the effectiveness of no-take zones for conservation. This work is providing many insights into how fish use the reef, and how much reef they use. For instance Spangled Emperor spend significant amounts of time near the shoreline within the lagoon, where they may be vulnerable to fishing, especially within special purpose shore based fishing zones. The question of whether this is a desirable outcome in terms of spillover for recreational shore-based fishers, or an undesirable one for conservation managers on the grounds of reduced conservation effectiveness is still to be decided.

Marine Parks are established not only to protect targeted species, but also to protect the entire ecosystem and its biodiversity. This is a core goal not only for conservation managers but also increasingly for fisheries managers. One way that no-take areas in Marine Parks can do this is by restoring balance to an ecosystem. Removing key predators has been shown in some ecosystems to have cascading indirect effects on grazing species, algae and corals, potentially changing reefs almost beyond recognition. Restoring predatory species can reverse these effects. The question for managers of Ningaloo is whether such effects are happening, and what is the potential for such effects to develop? Providing answers to questions such as these provides a much more concrete answer to whether the zones are working than an arbitrary measure of how many times more fish may be there. Some indirect effects of fishing do seem to be present on Ningaloo, but so far they seem to be relatively small. Of most interest from the scientific point of view, but also potentially for management, is that the indirect effects of fishing are not of the kind we first predicted, and are instead seen in grazing fish rather than invertebrates. We are still trying to determine the exact mechanisms underlying these results, but it seems likely that they will provide new insights into mechanisms that underpin the stability and resilience of coral reef ecosystems.

While most of the questions addressed in the research outlined above, and in most research related to no-take areas world-wide relate mainly to no-take zones themselves, the responsibilities of management in large multiple-use marine parks extend to the whole park. For instance, the conservation benefits of no-take areas may be outweighed or even eroded if the fish population in the rest of the park are not being well managed. One reason for this is that the fish population as a functional unit extends throughout the park and beyond it. That is why the NRP asks what management strategies will be most effective in maintaining the fish population health throughout the park? This is a question relevant to not only conservation managers but also to fisheries managers. Surveys show that the numbers of fish throughout the park do appear to reflect differences in fishing pressure, and are lower where there is greater fishing pressure, but these are only a relative measure. Such comparisons don't tell us whether the population as a whole is headed up or down. In order to begin to answer such larger scale and longer term questions, we need to use approaches such as population modelling that can begin to tell us what fish numbers are likely to have been in the past, and how they may change in the future, given certain scenarios. Other scientific approaches that need to be used in conjunction with modelling are long term measurements of fish density and of key aspects of fish biology. Both of these methods have been applied in recent research at Ningaloo by the NRP and by WA Fisheries. Insights from modelling suggest that management outside the no-take areas if just as important as management inside them. There is increasing alignment between the mandates of conservation and fisheries agencies and both will need to work towards common goals in order to ensure healthy fish populations and healthy ecosystems into the future.

Overview

Sustainable Fisheries Management – Integration of science into management

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Sustainable fisheries management involves the integration of biological, ecological and socio-economic objectives. It follows the principles of the *Fisheries Resources Management Act 1994* but also incorporates Ecologically Sustainable Development (ESD) principles, Integrated Fisheries Management (IFM) and the concept of Ecosystem Based Fisheries Management (EBFM).

Implementing ESD in fisheries means that we not only need to consider the effects of the fishery on the target species, but also what effects there may be on the rest of the ecosystem. We also need to recognise the economic health of a fishery (such as the profits to commercial fishers or the satisfaction of recreational fishers) relies on maintaining essential ecological processes. Furthermore, the ongoing utilisation of fishery resources requires the community to be satisfied with the management of the fishery and be convinced that it is providing sufficient social and/or economic benefits to justify any negative impacts it may have. Finally, the processes and procedures involved in managing a fishery (its governance) have to be appropriate to meet the ESD challenge.

In essence, the management objectives are:

- Biological/ecological
  - o ensuring the maintenance of breeding stock;
  - o ensure management arrangements are consistent with the principles of ecosystem-based management and in particular:
    - – bycatch is minimised
    - – effects of fishing do not result in irreversible changes to the ecological processes.
- Socio-economic -maximise the opportunity for optimum economic returns to the Western Australian community from the use of the resource, and foster the maintenance and development of regional communities while not unnecessarily restricting normal business practices.

Since 2004, the Government has also adopted the concept of IFM with the formal process involving:

- setting the total sustainable harvest level of each resource that allows for an ecologically sustainable level of fishing;
- allocation of explicit catch shares for use by commercial, recreational and Indigenous fishers;
- continual monitoring of each sector's harvested catch;
- managing each sector within its allocated catch share;
- developing mechanisms to enable the reallocation of catch shares between sectors.

This process is yet to be formally implemented in many fisheries/bioregions.

In recent years management of fisheries within bioregions has gained prominence and therefore not only individual fisheries are considered but also the combined interactions of multi-species fisheries and their associated habitats/ecosystems. A risk assessment of the West Coast bioregion has been completed and the Gascoyne Bioregion including the Ningaloo Coast will be next. Within this context, other non-direct fishery influences are also considered (e.g. marine planning, coastal development, population growth, world economy).

The relevant issues for the fishery/bioregion under consideration can be identified (through component trees) and the risks associated with each issue determined. Risk assessment methodology has been adapted to assist in determining the relative priority of issues and specifying an appropriate level of management response.

Good management is underpinned by good science. The complexity of ecosystems and the demand to better understand fishery dynamics, effects of fishing on ecosystems/habitats, impacts of the environment of fisheries and their habitats and the socio-economic implications provides challenges to fisheries scientists and ecologists in the provision of rigorous, robust science to address management needs as well as the need to communicate the science to managers and the community/stakeholders. For some fisheries and regions there is extensive research and catch monitoring whereas for other fisheries less information is available and the level of information on habitats, biodiversity and ecosystems is generally much less.

The process of integration of the science (species distribution (catch, byproduct, bycatch), life history characteristics, recruitment, growth, feeding, habitat preferences, physical environment, fishing impacts, stock assessment, catch predictions, modeling, climate change) to address management objectives is achieved through communication and participation of scientists (both fisheries and collaborators), managers and stakeholders in decision-making. Examples of the research conducted and how results have been incorporated into management processes are described for some of the States fisheries including the Gascoyne scalefish sustainability program (focusing on Ningaloo Marine Park region) and the Exmouth Gulf prawn fishery.

Overview

Informing Natural Resource Management

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Abstract

Resource management has been a human concern for at least 4000 years. During this long history the most effective and robust form of management has been well implemented and supported adaptive (“detect and correct”) management. This form of management is the one best suited to the ever shifting nature of social-ecological systems, but is dependent on good supporting information (good science). One useful way to highlight the many potential strengths and hurdles associated with using science to inform natural resource management is to step through a “living example” – such as tourism on Ningaloo. In trying to plan for, support and regulate tourism activities managers would like to know “how many people could Ningaloo support?” Behind this request is a desire for knowledge on potential revenues, but also associated costs, impacts and impediments. The information required to adequately address the question quickly expands to include the state of the natural resources, capacity of different locations, pressures associated with different activities (and tradeoffs between them), preferences of different tourist types, access, infrastructure, water, waste handling, labour, housing, supplies, competition and the interaction with other sectors. If researchers can access the data, science has a positive role in deciphering this complexity, identifying useful management strategies and highlighting cost effective research and monitoring opportunities. However, the benefits of this information will only be realised if scientists can engage managers (and other resource users) with information they can interpret and incorporate into their decision making process. A worked example is presented based around Ningaloo reef.

Introduction

Resource management has been a topic of regulatory concern since the earliest administrative records were laid down 3500-5000 years ago (e.g. decrees of Samsu-iluna from roughly 1720 BC). Today many planning and regulatory bodies around the world have foundation documents that begin with statements like “…sustainable management of… natural resources (our land, water, marine and biological systems) is vital if we are to ensure our ongoing social, economic and environmental wellbeing” (Australian Government NRM website 2008 - http://www.nrm.gov.au/nrm/index.html). Non-government organisations and government departments typically aim to support (regional) plans and strategic programs of investment and development supported by local communities. They seek to develop capacity, markets, environmental management systems and on-going monitoring and evaluation processes. This desire to set objectives for the system, to act and then to evaluate and respond to the outcomes is congruent with the principle of adaptive management (Figure 1). This form of management can be characterised as “learning by doing” or “detect and correct”. It was formalised in the 1970s and 1980s (Holling 1978, Walters 1986) and was first applied to fisheries and other targeted natural resources like forestry (Jones 2005).

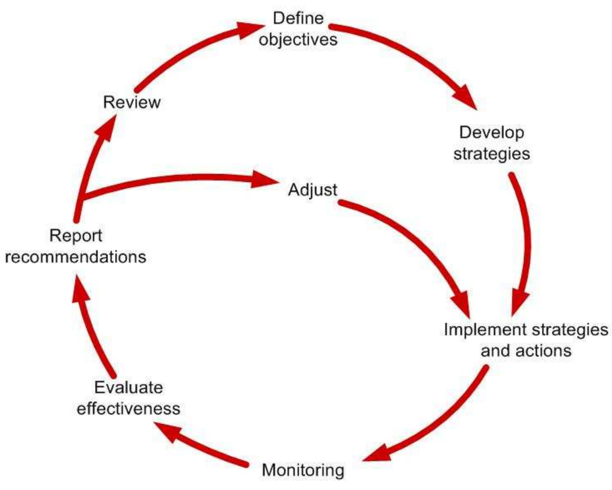

Figure 1: The adaptive management cycle (modified from Jones 2005).

Within the last decade its use has expanded to multiple use management, drawing in all sectors dependent on natural resources. Originally developed to facilitate management (and build understanding) under uncertainty, the approach allows for movement away from the idea of equilibrium systems that there is some static "best" state and can embrace the dynamic nature of social-ecological systems. This makes it particularly suited to allowing management to adapt to shifts in systems (e.g. due to climate change or changing social attitudes). However, this flexibility and the iterative nature of the decision making loop in adaptive management presents scientists and managers with a two edged sword. The management approach can benefit significantly from the increased understanding that scientific information can supply, but only if it can be accessed and understood by managers.

A worked example

Tourism on Ningaloo

In the spirit of "learning by doing" the issues with science in support of management are probably best demonstrated by a worked example, in this case one based on tourism in the Ningaloo region. Figure 2 is a simplified diagram of all the interacting aspects and drivers of tourism and associated planning and development. Even in this simplified version the simple question of "how many people could Ningaloo support?", it is clear that information is required on a diverse range of topics, including: state of the natural resources, capacity of different locations, pressures associated with different activities, tradeoffs between activities, tourist (and local) preferences, access and infrastructure, water, waste, labour, housing, supplies, as well as cross sector social and economic competition and interaction. Managers at different levels and in different departments or jurisdictions may require answers regarding specific aspects of the system or they may need more general or high-level answers. For instance, while some managers are asking whether tourism and a flourishing mining industry are incompatible, others are more concerned with: (i) the value and risks associated with the placement of closed areas; (ii) water allocation and (iii) whether desalinisation plants provide a cost effective solution; and (iv) the implications of marketing, shifting user base and spectrum creep. Scientists can support these managers and their different needs in a range of ways; from targeted tools that explicitly address a constrained subset of the system and associated management questions, through to broader tools that can give strategic insight across all the dynamic components in the system. The research based around Ningaloo provides good examples of both the targeted and broad tools.

Integrating science

One way science can integrate information on a system is via modelling. Whether conceptual, qualitative or quantitative, models allow for information on a system to be laid down in a common framework – which can increase understanding of driving mechanisms, highlight major gaps in knowledge, and provide an arena for 'road testing' ideas before implementing them in reality. A wide range of models for Ningaloo have been developed by WAMSI and the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster researchers. Some of these focus on specific ecosystem components (e.g. hydrodynamics and water flow along the reef, or how tourists make decisions on where to visit) while others span many components (e.g. fishing, fish and habitat model or the tourism destination and load model). Together these modelling efforts provide complementary information about the system, highlighting different aspects of the systems and the interactions within it. The Management Strategy Evaluation (MSE) model is the broadest model of all, bringing all the components together to allow for "what if" testing of alternative future scenarios and management strategies and highlighting tradeoffs between the demands of the different sectors active in the region.

MSE is a good example of how to integrate science into tools for supporting management. The process starts by consulting with a wide range of people interested in the system and asking them for the objectives for the system and any proposed management ideas. The entire system is then simulated, including the natural world, the sectors (people) using it, how it is monitored and assessed and finally how management is implemented and updated. The crucial aspect of these simulations is to capture the range of shifting ecological, social and economic processes in the system that can lead to feedbacks and unexpected changes. The output of the simulations is reported in a style emphasising which objectives were met under particular circumstances. No optimal solution is provided, instead information is supplied and decisions left to management groups.

In the case of Ningaloo tourism, consultation with users and managers of Ningaloo has identified the questions listed in Figure 2 (and more). A complex agent based model (InVitro) – which captures critical components in the system (Figure 3) using a combination of the classical mathematical approaches of Newton with approaches more akin to those used in videogames – is being developed to "play out" alternative futures and highlight strengths and drawbacks with a range of potential management actions (Table 1). In the past questions may have been confined to a single industry, like tourism, but in the multiple use management context of Ningaloo, tourism will be only one of many sectors for which questions will be asked. Ultimately management questions for Ningaloo will need to consider interactions and tensions between all facets of the system.

Table 1: List of potential management actions associated with tourism to consider for the Ningaloo region.

Management Action
Sustainability strategies
1. What is the vulnerability of the industry to environmental impacts from accidents in other sectors or external environmental/economic/political shocks?
2. Can reducing environmental load (via use of more eco-efficient practices and technology) increase the sustainability of regional development? Even under climate change?
3. Can environmental loads and social pressures associated with regional development be mitigated by controlling the kinds of activities (or level of usage) allowed?
4. What are the implications of centralised enforced patterns of adoption vs market adoption of technology?
5. Can the pattern (and timing) of development improve sustainability (large release vs controlled growth)?
6. What are the cumulative impacts and benefits of development?
7. Are there long-term costs to short term decisions to "gain sustainability"?
8. Is there a limit to the area that can be developed?
Governance strategies
9. What are the impacts of changes in governance over accommodation and activities?
10. What are the implications of concentrated (but potentially intense) use of the system vs dispersed use with less site-by-site infrastructure?
11. What are the implications of open vs controlled access to different areas or activities? Implications of expansion of associated infrastructure? Both with regard to load, but also costs of monitoring and management.
12. Are there implications of a once off release versus a trickle of growth versus an adaptive sequence of releases (based on evaluation of previous releases) with regard to meeting management objectives?
13. What are the implications of development and zoning decisions for residents of regional centres?
14. What are the implications of different management methods and activity mixes for the triple bottom line (ecological, economic, social outcomes)?
Monitoring strategies
15. What are the implications of different kinds of monitoring schemes and infrastructure development (pulses of funding vs continuous lower level funding)?
16. What should be monitored? What is the loss associated with monitoring fewer sites?

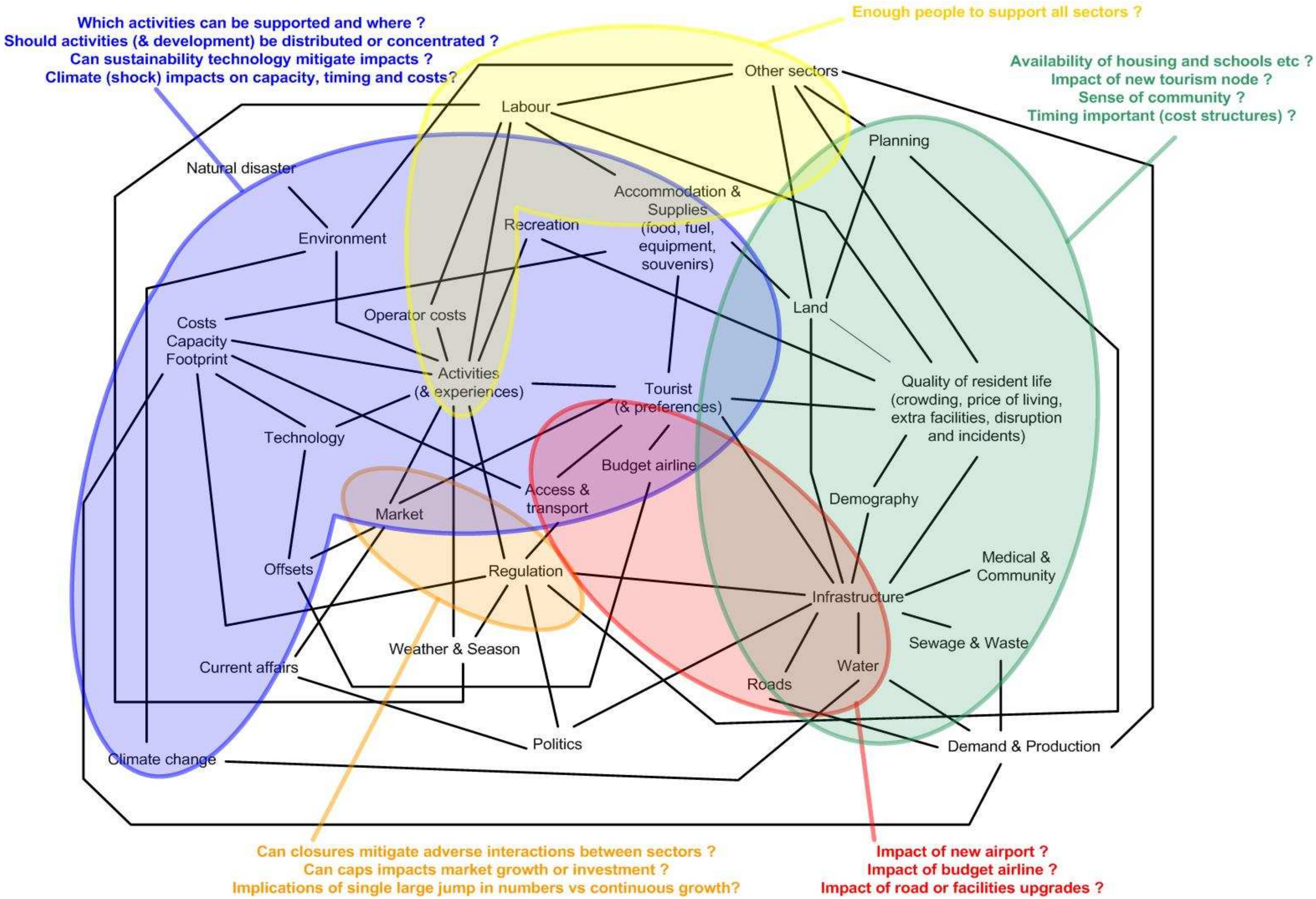

Figure 2: Diagram of drivers and processes associated with tourism, planning and development. Pertinent management questions are also given in the coloured bubbles.

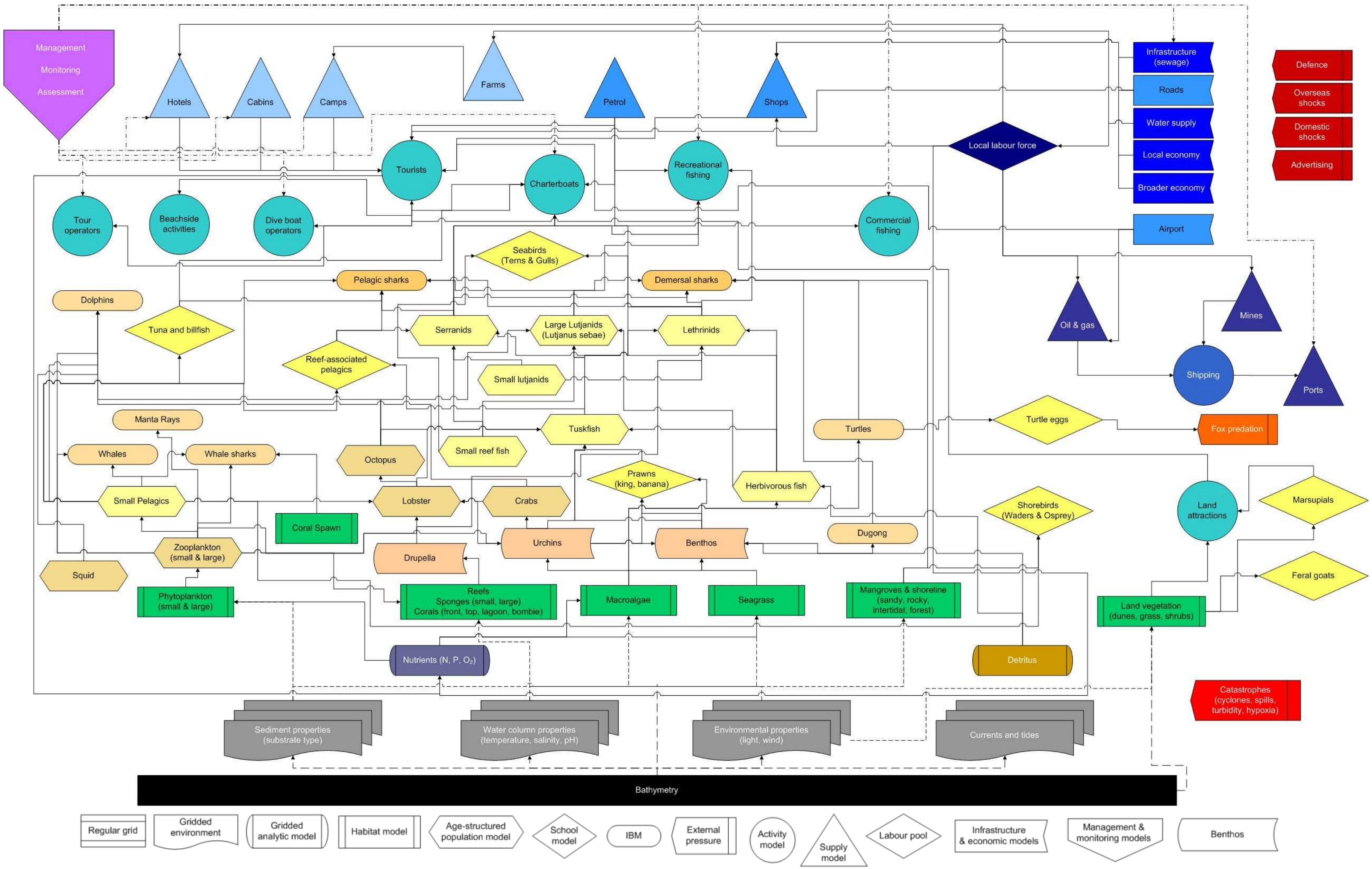

Figure 3: Diagram of components for an agent based model of Ningaloo.

Benefits of using science

While scientific tools such as the MSE model can appear dauntingly complex, they can clarify system understanding (as you can break apart models and tease out function in ways you can't with real systems). They can also lay out potential outcomes and are particularly good at putting a spot light on contradictory and uncertain or missing information. All of this can help managers make informed decisions, including the true value and form of cost effective research and monitoring opportunities. This is a clear example of how science can directly support monitoring, learning and decision-making segments of adaptive management.

Greatest hurdles

Science can only support management if it can successfully supply relevant information, which directly informs the process. Anything that prevents this will derail the value of science for management (potential failure points are summarised in Figure 4). Perhaps the most common ways that science can fail to inform management (Elzinga et al. 1998, Lee 1999) are:

1. If science can't access data on the systems components in question (either because the data has not been collected or because it is held in confidence) attempts to support management will not even get off the ground.
2. If scientists don't engage with managers (and other resource users) they will either fail to ask useful questions (and so will be of little use to management) or they will not be sure of a clear pathway of delivering information to decision makers.
3. If information is not presented in a way that managers (and other resource users) can interpret and understand they will fail to incorporate it into their decision making process.

While all three of these forms of failure are significant, the last is potentially the most common and the most disappointing. Given the effort and funds put into monitoring and research it is important to make sure the results are clearly articulated. Inconclusive results (that do not give clear indications for managers either way) can not be guaranteed against and managers will always have to act in the context of external political and social considerations, but effort must be put into effective communication of results. Much like an information onion scientists need to strip away the overwhelming volume of complex information they collect to leave the key findings that are presented in a way that pertinent information (and an indication of uncertainty) is retained while also being in a form managers and resource users can interpret and directly incorporate into their decision making processes. If people can not understand the messages from science, or do not feel they can trust them, then they will not use them. The use of approaches like "traffic lights" (Figure 5a,b; Caddy 2002) or kite plots (Figure 5c; modified form the AMOEBA approach of Laane and Peters 1993 and Collie *et al* 2003) that put all the objectives on an equal footing (and avoid issues of trying to convert "apples" and "oranges" into a common currency) show a lot of promise. Nevertheless this is an on-going issue, because the communication step, perhaps beyond all others, is key to seeing the information science can supply transformed into learning and effective adaptive resource management.

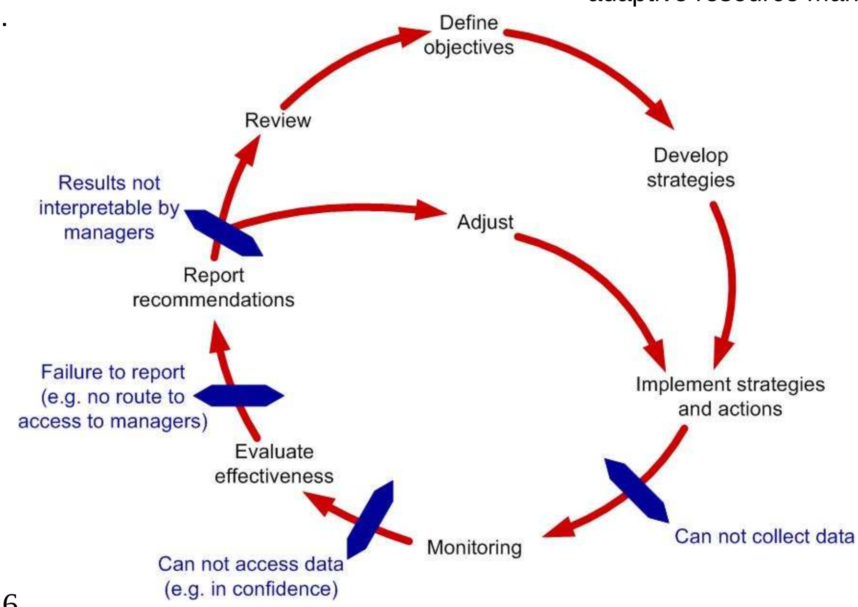

Figure 4: Failure points (marked in blue) in adaptive management cycle.

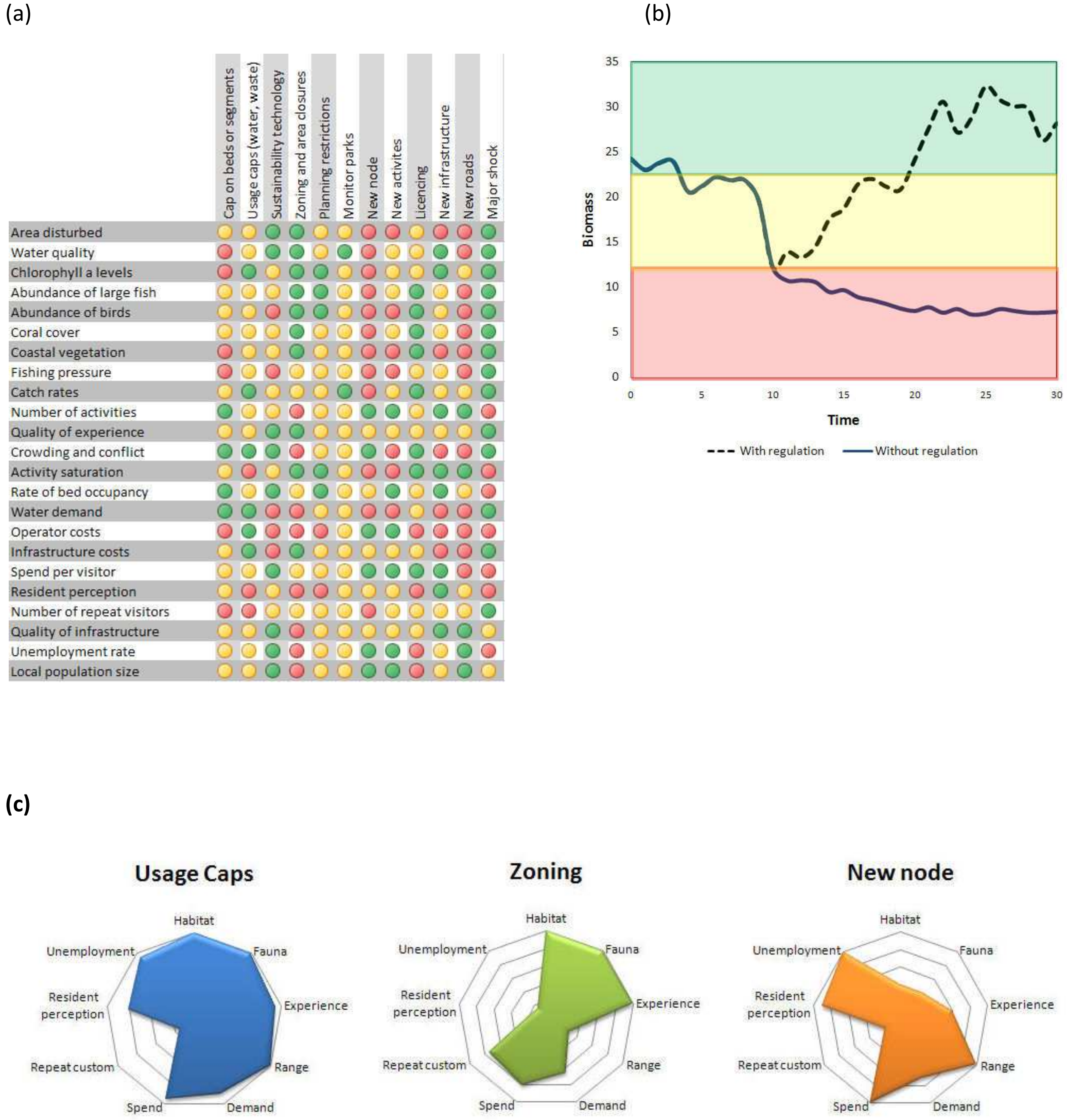

Figure 5: Example reporting approaches: (a) endpoint traffic lights for individual objectives (where red is poor and green is good performance relative to objective); (b) traffic light classification of time series (red-green as for traffic lights); and (c) kite plots for the various objectives (where a value on the boundary of the kite reflects good performance vs that objective and a value toward the centre of the kite is poor performance). Note these figures are for demonstration only and do not reflect actual model output (as the MSE simulation project is not yet complete).

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Overview

"The Key Natural Resource Management Questions" - A regional context for Exmouth and Ningaloo

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Marine resource management in the broader Exmouth region has a history of nearly 50 years supported significantly by ongoing interest in science. The cornerstones of management decision making falls principally in three broad areas; in the application of fisheries management, the conservation and management of the marine estate, notably the Ningaloo Marine Park and the minimisation of the impact of human activity on the environment. The impacts of significance include fishing and boating, recreational tourism, coastal development, petroleum and mining production and infrastructure provision.

The significant regional players include the Department of Environment and Conservation, the Department of Fisheries, the Environmental Protection Authority, Local Government and the Department of Mines. Each organisation having a plethora of roles and responsibilities supported and impacted by governing legislation.

Management decision making is not undertaken in a vacuum but within a political, economic and social mix of considerable complexity supported by executive government represented by State and Commonwealth Ministers, and Cabinets under the accountabilities of parliaments and the judiciary.

Decision making by natural resource managers must operated in this context and by their very nature are multilayered, interdependent and with objectives and related strategies between various competing uses of natural resources, not always aligned and at times in conflict.

The significant questions facing policy and natural resource managers include some of the following:-

1. What is the best use of natural resources by the community or visitors of it now and into the future?
2. How can fisheries expectations by commercial and recreational fishers be undertaken sustainably for optimum community benefit?
3. Can diversity of our marine environment be maintained and if so how best to deliver this outcome?
4. Should new industries or new developments be allowed to proceed, under what conditions and how are impacts on other industries or the community ameliorated and mitigated?
5. What will be the likely impact of climate change on each of these issues and when?

Noting there is currently a $30 million multi-discipline science lead research program on Ningaloo, equally there is a range of lower level operational and strategic questions of importance for natural resource managers.

Two brief case examples are presented on significant marine natural resource manager issues for the region. The first relates to a current proposal for a new salt mining development by Strait Resources and issues emanating from this proposal for the Exmouth region. The second relates to operational issues for the Ningaloo Marine Park and ongoing management needs for the park.

These examples by way of introduction underpin the importance of science in influencing management outcomes. The need for natural resource managers and the community to understand the science and its implication for management is of paramount importance to facilitate better decisions and improve community and political acceptability. Communication is key!

Finally comment is made on the increasing use of risk assessment based frameworks in the support of decision making in natural resource management fields. Science and research has significant costs and decisions impacting on the community cannot be deferred. Uncertainty needs to be better taken into account in ongoing development of evaluation tools in linking science to management outcomes.

The use of such tools appears to be the trend in a number of natural resource management fields. It is the case for fisheries management, increasing the case for Environmental Protection Agency assessments and from the work led by CSIRO and presented today for marine park management.

Overview

Science and Management in land use and planning

David Wood

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Planning and management at Ningaloo has evolved to meet the pressures of incremental development in the region following the establishment of the Exmouth town site in the early 1960s to service the Harold E Holt Communications base on North West Cape. The town site brought population pressures to hitherto remote, sparsely populated station country that was variously also used for defences, whaling operations and recreation for station owners from the hinterland.

In 1965, soon after the establishment of Exmouth, Cape Range National Park was gazetted and gazettal was followed by the development of a Management Plan to not only protect the natural environment but also to make it accessible to the townsfolk and communications base workers. Later, the State established the Ningaloo Marine Park and set about managing use of and visitation to Ningaloo Reef. The management plan for the Marine Park is, like that for Cape Range, a plan for use of a natural resource for human visitation.

Whilst the State set about managing the natural environment, it also sought to plan for land use to facilitate growth in Exmouth and later, along the Ningaloo Coast between Carnarvon and Exmouth. However, the impetus for land use planning and the injection of planning resources was subdued until a projected development at Maud’s Landing, immediately north of Cora Bay, raised concerns amongst communities throughout Western Australia and later nationally and internationally, leading to the ‘Save Ningaloo’ campaign. The Maud’s Landing development proposals were eventually rejected by the then Premier of Western Australia, Dr Geoff Gallop, and the State then developed a comprehensive land use plan for the region supported by protection measures, resources and a cooperative governance system; the Ningaloo Sustainable Development Committee.

A recent change in government, in Western Australia, has renewed the focus of many on development at Ningaloo. The Ningaloo Sustainable Development Committee will be dissolved in favour of a new Gascoyne coast Regional Planning Committee, the Ningaloo Sustainable Development Office will close in late May and rumours abound concerning the future of a two kilometre coastal exclusion zone designed to protect the Ningaloo Coast and make it accessible to all Western Australians and visitors to the State. There is even speculation that the Maud’s Landing development proposal could re-emerge. This uncertainty arises at a time when research has heightened our understanding of Ningaloo and the interaction between its users and its fragile natural environments, a time when research proposes concrete management and planning solutions.

This presentation will examine the history of planning and management at Ningaloo and seek to stimulate discussion about the contribution of research to the future of Ningaloo, its users, local communities and its fragile natural environments.

ABSTRACTS FOR

ORAL PRESENTATIONS

Fish surveys across Ningaloo and the effectiveness of the current zoning of the marine park

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

CSIRO Wealth from Oceans National Research Flagship, Marine and Atmospheric Research, Cleveland, QLD

Populations of fish targeted by recreational fishers in the Ningaloo Marine Park were surveyed in 2006 and 2007 to assess whether populations in pre-existing sanctuary zones (established in 1987) differed from those in areas that were open to fishing. Herbivorous fish from major families in this functional group were also counted. 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.

Fish assemblage structure showed clear trends with habitat and from north to south. There was also a significant overall difference in fish assemblages inside and outside sanctuary zones. The zoning related patterns appeared to be complex however, and examination of assemblages on a region by region basis showed zoning-related patterns in assemblages at only three sites, where targeted species were among those most likely to explain observed differences in assemblages. Non-target groups, including large grazers (parrot fish and drummers) were also associated with these differences. Among the species most commonly targeted by anglers there was an overall increase in biomass for the yellow tailed emperor (*L. atkinsoni*) which was between 0.9 and 2.4 times greater in pre-existing sanctuary zones, as well as in the spangled emperor (*L. nebulosus*) with biomass between 0.4 and 2.8 times greater (Fig. 1). These trends in fish biomass were largely driven by the size structure of populations in sanctuary zones. The trends in both of these species were strongest in the in fish greater than the minimum legal size, consistent with fishing being the factor driving these differences. Other species that showed significant biomass increases in sanctuary zone areas were the Chinaman Cod *Epinephelus rivulatus* in regions in which pre-existing sanctuaries were present, and Mangrove Jack *Lutjanus argentimaculatus* at the Exmouth Gulf region at Bundegi, where this species is more widely distributed than on Ningaloo Reef proper.

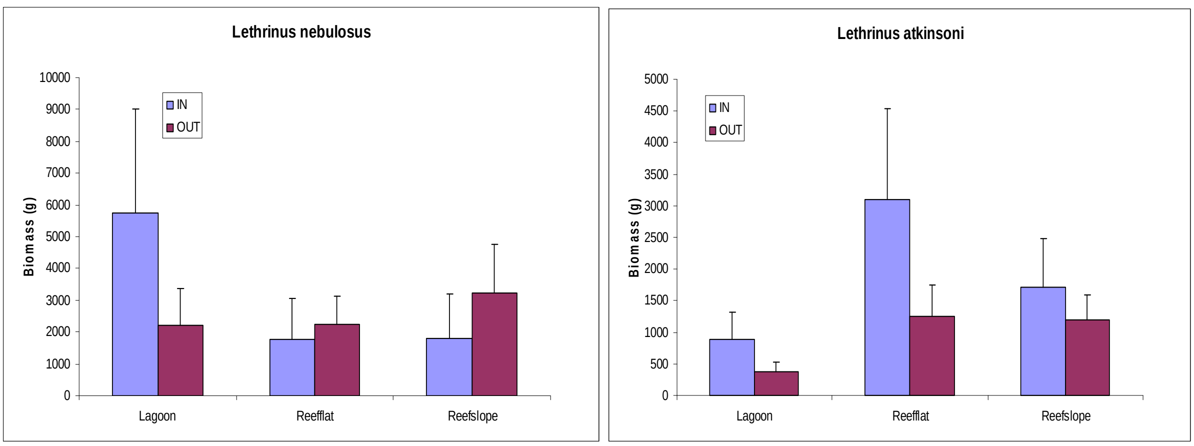

Figure 1. Biomass of Emperor species across Ningaloo Marine Park.

Other species commonly targeted by recreational fishers were significantly more common outside sanctuary zones than inside them. The reasons for this are unclear but are likely to be complex, relating to the uneven distribution of habitat among pre-existing sanctuary zones and open areas, movements and habitat preferences of these species, as well as the distribution of fishing effort around the reef. Most of these species are strongly associated with reef slope habitats which have been relatively poorly represented in pre-existing zones. Significant trends in relation to fishing pressure were nevertheless present among many of these species, which included large groupers and sharks, with biomass tending to be significantly lower in areas with higher levels of recreational fishing pressure (Figures 2, 3).

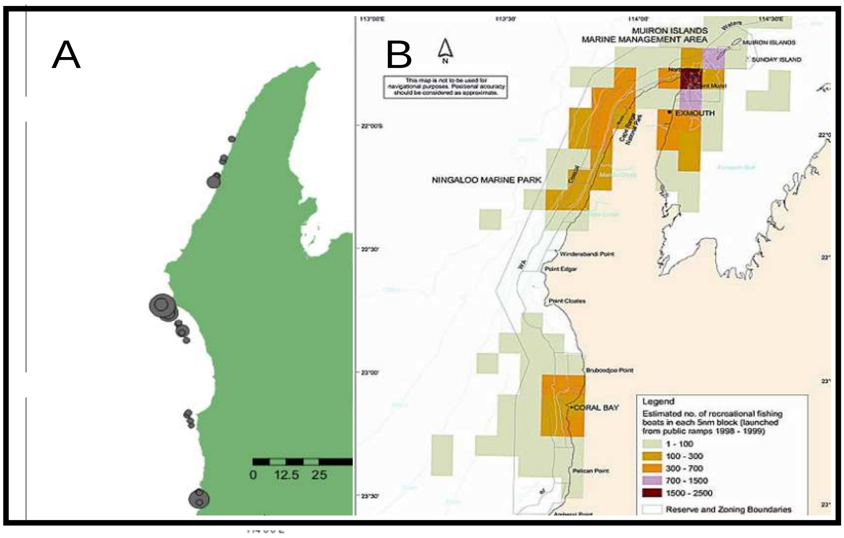

Figure 2. (A) Abundance (per UVC transect) of the gray reef Shark (*Carcharhinus amblyrhynchos*) and (B) distribution of fishing effort around in the Ningaloo Marine Park and western Exmouth Gulf (boats per year in each 6 nm reporting block based on boat ramp surveys in 1999; from Sumner 2002).

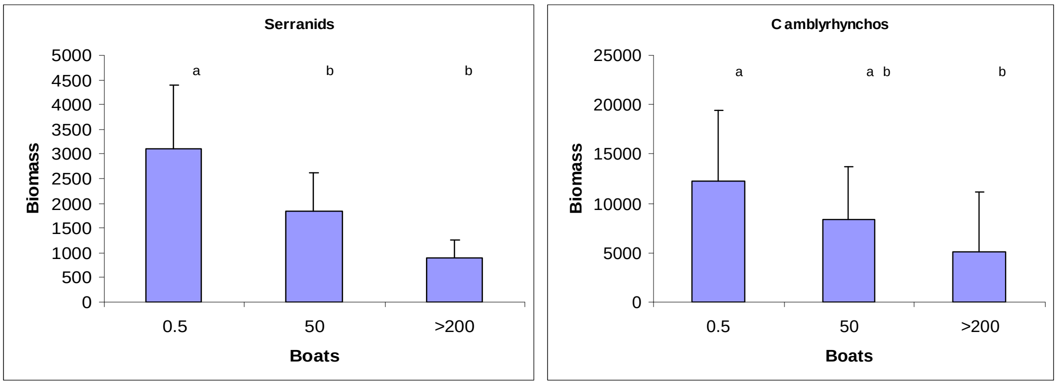

Figure 3. Biomass of Large Grouper (Serranidae) and Grey Reef Sharks (*C. amblyrhynchos*) in the Ningaloo Marine Park relative to fishing pressure. Biomass data are means per transect (g + 95% CI), Fishing effort is boats per year from all 6nm statistical reporting blocks (Sumner et al 2002) in which data were collected. Significant overall variation in biomass was present in relation to fishing pressure for all groups except tuskfish. Letters indicate levels of fishing pressure shown to differ in the basis of pairwise comparisons.

Comparisons among reserves of different sizes showed no clear trends in effectiveness of zones with respect to the size of sanctuary zones. At Osprey sanctuary zone there appeared to be fewer *L. nebulosus* than had been measured in surveys in 1987. The downward trend in abundance was smaller in the Osprey sanctuary zone sites than in the adjacent fished sites.

The sampling methods employed delivered a high level of statistical power and allowed and examination of effects along the entire extent of the marine park as well as within individual regions. They provide the basis for the design of an ongoing monitoring and research program which should take advantage of recent developments in sampling design that will allow for systematic rotation of sampling and offer greater economy and precision and provide the most accurate possible estimates of absolute population density. The design should use the latest information (e.g. from the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster) for stratification of sampling among habitats. Future monitoring related research should include cross-calibration of deep water BRUV (baited remote underwater video) and shallow water UVC (underwater visual census) sampling. Other research needs highlighted by this project include the need to further investigate the potential for indirect effects of fishing due to apparent effects on shark populations in the Park.

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

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Understanding where, when, and how many people use the coast is imperative for management of natural coastal assets, conservation of marine biodiversity and location of appropriate infrastructure. This CSIRO Wealth from Oceans National Research project is aimed at determining the spatial and temporal distribution of recreational activities within the reef lagoon system at Ningaloo Marine Park (NMP), and relating these patterns to factors such as biodiversity, geomorphology, park zoning, access roads and accommodation nodes. During 2007, 34 geo-referenced aerial surveys conducted throughout the year along the entire 300 km length of the NMP identified a clear seasonal pattern of boating and coastal use with well-defined expansion and contraction of the spatial extent of recreational activities from nodes like Exmouth and Coral Bay. Similarly, 192 land-based surveys provided high resolution geo-referenced data on the recreational activities undertaken by the visitors in the NMP (32% were relaxing on the beaches, 15% walking, 11% snorkelling, 8% shore-fishing, 7% swimming and the remainder involved in a wide range of other pursuits). While some activities were ubiquitous throughout accessible areas of the NMP, others were dependent on the biophysical attributes of particular sites. In addition, interviews with >1 200 people engaged in recreational activities in the NMP allowed identification of travel networks and site-specific usage patterns. Indicators that could be used by managers to monitor usage of the NMP have been explored with due regard to existing management protocols. These include surrogates like cars parked adjacent to the NMP, occupancy of campsites and numbers of boat trailers at boat ramps. The quantitative information from the mapping project provides a robust baseline of human usage of the NMP under the 2005-2015 management plan and has potential for assisting in predicting response to changes in coastal infrastructure and management policy.

Towards a Global Biodiversity Baseline for Coral Reefs

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Coral reefs are the most biologically diverse and threatened marine ecosystems on the planet. Yet, beyond select groups, particularly corals and fishes, we know very little about what lives on coral reefs, even to an order of magnitude of the number of species that inhabit them. Recent research also indicates that the groups for which we have reasonably good information are unlikely to act as robust surrogates for the groups that are poorly known. In order to effectively conserve and manage these biological resources effectively, it is necessary to establish a biodiversity baseline against which reefs of the future can be compared. Without this baseline, it will be impossible to assess the effectiveness of management actions. The CReefs project of the international Census of Marine Life is working to help establish this benchmark, both through the facilitation of taxonomic and biogeographic research of lesser-known groups on coral reefs and the development and deployment of methods for standardised sampling and analysis of coral reef biodiversity.

Current status of the invertebrate fauna targeted by fishers and the possible outcomes of different management alternatives.

Martial Depczynski[1], Andrew Heyward[1] & Ben Radford[1]
Russ Babcock[2] & Mick Haywood[2]

[1]Austalian Institute of Marine Science, The University of Western Australia, Crawley, WA
[2]CSIRO Wealth from Oceans National Research Flagship, Marine and Atmospheric Research, Cleveland, QLD

A series of field trips were conducted by AIMS and CSIRO between 2006 and 2009 from North West Cape to Turtles Sanctuary to address the following objectives;

1) Determination of the stock status for targeted invertebrate species along the length of Ningaloo Marine Park including octopus and rock lobster.

2) Characterising habitats associated with high numbers of these targeted species.

3) A comparison of stock abundance in relation to differing levels of visitor pressure.

Rock lobster

The abundance of all five species of lobsters were very low (approximately one individual / km^2), however there were regions that held significantly higher abundances. The patchy nature of their current patterns of distribution appears to be most tightly correlated with habitat characteristics and the age of sanctuary zones. In addition, geographic remoteness, the types of activities pursued by visitors and corresponding levels of fishing pressure at different locations along the Marine Park are also likely to play a major role in the patterns seen today and the determination of future lobster populations.

Ningaloo once supported a commercial rock lobster fishery during the 60's - 70's that extracted approximately 25,000-30,000 individuals each year within six month periods. Today, it seems clear that the rock lobster population of Ningaloo Reef is a shadow of both its carrying capacity and its former self. However, there is hope. While larval lobster numbers throughout WA have been in steep decline over the last few years, puerulus collectors at Quobba Station just south of the Ningaloo Marine Park are exceptional in that they have been experiencing increases. Given these facts, it seems imperative that a continued monitoring presence of the Park's adult and larval Rock lobster populations be maintained at this critical moment in time and that additional measures to preserve the existing Ningaloo stock be created.

Octopi

Octopus abundance throughout the marine park were also quite low and characterised by a reasonable presence in just a few select areas. However, their behaviourally and visually cryptic nature makes accurate determination of numbers difficult. Throughout the marine park, octopi are targeted for bait and their habitat requirements for shallow sub- and intertidal reefs with adequate hiding dens are quite specific. There are not many areas along the Park that fulfill these requirements well. In addition, low spring tides provide an easy opportunity to harvest octopi from these limited areas. Evidence from patterns of distribution of the same species (Octopus cyanea) in Africa indicates that the densities and carrying capacities of the species are well above those found at Ningaloo. The cessation of fishing for octopus in (at least) a few key areas of the Park would allow a realistic evaluation of natural abundances, turnover and general population dynamics. However, in the absence of total closure to fishing of these areas, emphasis should rather go to a better understanding of their life histories to determine their vulnerability to human fishing pressure rather than conducting field surveys to try and accurately determine numbers.

Are there indirect effects of fishing on the Ningaloo Ecosystem?

Mat Vanderklift, Russ Babcock

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Shallow reef habitats are extensive along the Ningaloo reef tract, and are typically mainly subject to recreational fishing (commercial fishing occurs in deeper water further offshore). In parts of Ningaloo that are readily accessible (e.g. near boat ramps) fishing intensity can be quite high (e.g. >40,000 fisher days from four public boat ramps in 1998-1999). Fishing activity does measurably reduce the abundance of some species at some places in Ningaloo reef (see earlier talk by Russ Babcock). In coral reefs elsewhere, reductions in the abundance of targeted fish species result in indirect changes to other parts of the ecosystem – i.e. 'trophic cascades', for example when herbivores that are prey of targeted fish increase in abundance.

In order to assess the presence of indirect effects of fishing at Ningaloo, we surveyed fish, large invertebrates, macroalgae and corals – evidence for indirect effects could be inferred if the abundance of predatory fish and their prey were negatively correlated. To provide a further test, we measured the intensity of processes that could be responsible (predation and grazing). We surveyed reef flat habitats at 48 sites in and around three sanctuary zones (Mandu, Osprey and Maud) in which fishing of all kinds is prohibited.

Overall fish biomass of fish was almost twice as high inside the sanctuary zones, and the difference was particularly pronounced at two sanctuaries (Maud and Mandu). Strong trends were reflected in the biomass of parrotfishes and wrasses, and weaker trends were evident for emperors. Higher biomasses were typically also associated with areas of intermediate structural complexity, but differences between fished and sanctuary areas were present even after this influence was taken into account.

No overall differences in biomass were present for key prey that could play major roles in trophic cascades (the herbivorous sea urchin *Echinometra mathaei* and the corallivorous gastropod *Drupella cornus*). In addition, measurements of the intensity of predation on these invertebrates yielded no differences between sanctuary and fished areas. Similarly, the biomass of macroalgae, and the intensity of grazing, did not vary overall between fished and sanctuary areas.

We found no patterns that suggest unequivocally that indirect effects of fishing are strongly influencing the ecological communities on the reef flats. However, we identified both anticipated (i.e. lower abundances of targeted emperors) and unanticipated (i.e. lower abundances of non-targeted parrotfishes) effects of fishing. The lower abundances of parrotfishes might have an influence on the ecosystem in the long term, as parrotfish abundance was strongly associated with the biomass of algae (little algae was present where parrotfish were abundant) – and so understanding the processes that lead to this pattern is likely to be important for determining management strategies. In addition, the strong influence of structural complexity on the overall biomass of fishes suggests that practices that act to decrease the availability of structure should also be the focus of management strategies.

Intertidal Invertebrates

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[2]School of Plant Biology, University of Western Australia, Crawley, WA

Our project on intertidal rocky platforms in Ningaloo Marine Park has four main aims:

(1) Document most of the species of macroinvertebrates that occur on the platforms.

(2) Obtain quantitative estimates of the distribution and abundance of the organisms that make up the ecological communities that occur on the platforms along the length of the Marine Park.

(3) Compare these communities of invertebrates in different years.

(4) Incorporate our quantitative estimates of abundances of the species over space and time in an analysis of how likely such sampling schemes will be able, for example, to detect spatial differences between sanctuary zones and utilized areas, and to detect temporal changes due to management actions.

So far, in 652 one square meter quadrats from 24 sites, we have counted 20,026 individuals, belonging to about 160 species, mostly gastropods, but including corals, anemones, bivalves, chitons, crabs, urchins, starfish and sea cucumbers. We are preparing an annotated pictorial field guide as a general aid to us and others for identifying this fauna.

The general pattern, at any site, or groups of sites, is that the more individuals examined, the more species are detected, and the rate of discovery of additional species continues to be substantial. This is because there are many rare species. In consequence, any sampling scheme will continue to discover species that have not been encountered before, and no constrained program of samples will reveal all the species.

A second feature of our data is that the numbers of species expected in samples of equivalent numbers of individuals is highest for sites in the northern parts of the Marine Park, and lowest in central parts. In our 2007 sampling of 18 sites, 45 of the species occurred only in the north part of the Marine Park, 15 were only in the southern part, and 12 in the central portion. There were 23 species common to the three regions and 22 species shared by two regions. Thus, at the gross level of presence and absence of particular species, there is considerable spatial variation, not unexpected because our set of sites spans more than two degrees of latitude. For this reason, among others, the most abundant, or functionally important, or focal species will differ among geographic regions, and these differences will have to be accommodated in any future procedures to detect spatial or temporal differences.

So far, our temporal sampling involves a small subset of four of the northern sites that we have sampled in August 2007 and November 2008, but these provide a glimpse at the relative sizes of spatial and temporal variability for two simple variables from the sampling. Analysis of variance for sites and time as random factors revealed differences for the interaction between site and time, as well as for differences among sites for number of individuals and number of species per one square meter. The variance components for sites were larger by about four times than the components for time or the interaction between sites and time, for number of individuals, and by almost nine times for number of species. This suggests that our sampling scheme of 20 one square meter quadrats per site may be sufficient to detect differences between sites, and for differences over time that vary depending on site.

We have one specific test of this involving samples at the sites inside and outside the sanctuary zone at Jurabi in November 2008; we sampled two rocky intertidal platforms (locations) at each site. This design with replicate locations nested within the two levels of zone is a simple, preliminary attempt at detecting an effect of the sanctuary, although it obviously requires more locations within levels of zone than just two, to provide appropriate power for a serious test of the Zone term (F 0.05, df 1,2 = 18.51). The fact that the Location (Zone) term is statistically significant reinforces the results of all our sampling to date: each platform, even if close to another, is rather different. The consequence of this feature of the intertidal rocky platforms at Ningaloo Marine Park for detecting effects of sanctuary zones is that many sites inside and outside will be required, perhaps more than there are, or that can be sampled under constraints of time and funding.

Another view of the large variation among sites in the assemblages of species that occur there comes from multivariate analyses that compare the relatives abundances of each of the species found in the samples from our sites taken in August 2007 (Principal Coordinate Analysis of the eighteen sites). The sites from north, middle, and south regions are roughly grouped together. A whelk, a mussel, a limpet and a chiton are associated with the sites at the extreme south, and a cone and a stromb with the north sites, and another cone and a cerith with the middle sites. However, there are large dissimilarities among sites within the three regions, even those that are close together spatially. These results reinforce the fact that the fauna differs among the three regions, and that the relative abundances of the species within regions is also very different.

We are assembling data sets on physical features of the sites from direct measurements at the sites and from aerial images and maps (e.g., tidal level, texture, aspect, exposure, size and isolation of the platforms) to establish the variety of habitats that rocky intertidal platforms provide. More importantly, we will determine whether these data help explain the variation in composition of the assemblages on the platforms.

Our study is incomplete, but the results have implications relevant to the management zones. Most of the macroinvertebrates on the intertidal rocky platforms are small, cryptic, and in low abundance, which means that surveys are labour-intensive, and we will never be able to detect all the species. Although we can detect differences among sites, local heterogeneity is substantial, which will make detecting differences between management zones difficult. Because short-term temporal variability is less than spatial variation, it remains unclear whether changes over longer times will be any easier to detect than spatial differences.

Biodiversity studies in the Ningaloo Reef lagoon

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As part of the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster program currently underway in Western Australia, this study aims to examine the habitats and biodiversity of lagoonal areas within Ningaloo Reef. Key habitat types were identified using information from hyperspectral remote sensing and were used to develop a stratified sampling approach. Two focal areas were selected, based on sanctuary zones within Ningaloo Marine Park: Osprey Bay in the north and Coral Bay in the central section; an additional site has recently been added at Gnaraloo in the south. A nested sampling programme was initiated within each location, consisting of surveying transects at different spatial scales: cross-reef transects (shore to back-reef) to identify major habitat types and boundaries between habitats; and finer-scale habitat surveys of biodiversity and abundance of different major groups of organisms, focussing on non-scleractinian cnidarians, macroalgae, sponges, echinoderms and molluscs. Three geomorphological categories have been sampled at each location: back-reef, lagoon and inner reef-flat. Ground-truthing was carried out on the extent of habitats along defined transects selected to maximize the diversity of each site. A nested quadrat sampling regime was used to validate remotely-sensed data with field-collected data.

Preliminary results confirm that the northern section of Ningaloo Reef differs greatly from the central section, with a greater diversity of habitats present in the broader lagoons in the south. Greater areas of coral are found close inshore and across the entire reef at the central location, compared with the northern section, which has a broad expanse of sand and limestone pavement before grading to corals further offshore (the back-reef and reef-crest). These differences in habitat may have implications on the overall biodiversity of the two locations.

A team led by Greg Skilleter (UQ) is determining the value and applicability of the maps showing the distribution of habitat categories, derived from the analysis of the hyperspectral data, as surrogates for the on-ground assessment of biodiversity across Ningaloo Reef. This involves detailed validation of selected substrate categories and then determining the extent to which these habitat categories can act as surrogates for non-substrate invertebrate species using the reef. The focus of this process is on macro-invertebrates including molluscs, echinoderms, soft coral and sponges. Substrate composition is being determined by detailed examination of 1 x 1 m sub-quadrats within the nested quadrat sample design already in use, based on a range of pre-selected substrate categories identified from the habitat maps produced from the processed hyperspectral imagery. The first field trip for this study was conducted in April-May 2009 and a second field trip is planned for July 2009.

Qualitative sampling for diversity of macro-invertebrates in targeted groups is being carried out at the three geographical locations within Ningaloo Marine Park, focusing on macroalgae, seagrasses, echinoderms, clams, soft corals and sponges. Sub-sampling for macro-invertebrates was conducted along 50 m transects, with counts of holothurians, urchins, the gastropod *Drupella cornus* and clams (*Tridacna* spp.). As some of these taxonomic groups have been targeted by concurrent programmes (especially C-Reefs), a synthesis report on distribution and abundance data available for Ningaloo Reef from all sources is being compiled, in consultation with WA Museum, AIMS and university researchers; it is anticipated that a draft of this report will be available by the end of 2009.

Evaluating Management Strategies for Line fishing in the Ningaloo Marine Park

Rich Little and David McDonald

CSIRO Wealth from Oceans National Research Flagship, Marine and Atmospheric Research, Hobart, Tasmania

The spatial, multi-species nature of coral reef fisheries makes them notoriously difficult to manage. We have developed a simulation model to examine the effect of different amounts of area closure, effort projections, recreational bag limits and other factors on the main recreational target species of Ningaloo Reef: spangled emperor *(Lethrinus nebulosus)*. The model is a spatially explicit, age-structured population model, called ELFSim. 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.

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. This is achieved by bringing a broad range of physical, biological and socio-economic information and process understanding from the NRP and the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster into an integrated framework. It also provides an effective interface with management.

The model results show the effects of historical fishing mortality, localised depletion of spangled emperor, and the potential effect of the sanctuary zones that are closed to fishing. They also show the expected recreational catches and catch rates under different projected effort and management scenarios in the future.

ELFSim is a valuable tool for Management Strategy Evaluation in a reef line fishery. 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.

Gascoyne Scalefish Sustainability

Ross Marriott

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The Department of Fisheries WA (DoF) has recently undertaken research on commercial and recreational fishing within the Ningaloo Marine Park and broader Gascoyne Coast bioregion (Shark Bay to Exmouth Gulf, inclusive) to assess the sustainability of fishing activities on demersal scalefish stocks. Assessments were undertaken to determine the sustainable levels of total catch for the key species. These levels of catch will be allocated equitably, through consultation with fishers and the broader community, between these sectors through the Integrated Fisheries Management (IFM) initiative. Accordingly, sustainability assessments for IFM consider the combined impacts of fishing on stocks of demersal scalefish stocks, rather than assessments of individual fisheries or sectors.

A risk assessment was undertaken prior to these sustainability assessments to determine which species should be selected as representative of the suite of demersal scalefish species caught and potentially impacted by fishing in the Gascoyne. Three “primary indicator species” were selected from this process for sustainability assessments: spangled emperor (*Lethrinus nebulosus*), pink snapper (*Pagrus auratus*) and goldband snapper (*Pristipomoides multidens*). Since this symposium is focussed on management of the Ningaloo Marine Park, this presentation will focus on assessment of spangled emperor in the Gascoyne, because this species is caught more often than the other two in the Marine Park.

The objectives of the research study on spangled emperor were:

i. to fill gaps in existing knowledge about its biology; and
ii. to understand fishing impacts on its populations.

Biological data were obtained between June 2006 to June 2008 from the landed catches of commercial, recreational and charter fishers and from fishery-independent surveys. Importantly, biological sampling from the recreational sector was integrated with the 2007/08 DoF Recreational Fishing Survey (RFS), so was distributed spatially and seasonally in direct proportion to observed fishing effort. Biological specimens donated by recreational fishers during RFS interviews were therefore assumed to be approximately representative, in aggregate, of the total catch structure, according to the premise that fishing effort was directly proportionate to fishing catches. The catch-at-length and catch-at-age distributions of spangled emperor were then analysed for stock assessment.

Sustainability assessments for spangled emperor were based on a “weight of evidence” approach (Wise *et al.,* 2007). This type of assessment incorporates information on the catches and biological catch compositions, along with the species’ life history characteristics, population dynamics and inherent susceptibility to fishing impacts. Estimates of *F,* the average level of instantaneous fishing mortality across the population age structure of spangled emperor, were related to pre-determined biological reference points. Accordingly, these levels of *F*, in combination with biological parameter estimates will soon be used for assessing the risk status for spangled emperor, which in turn will be used by DoF managers to determine management strategies for sustainable fishing in the future.

Results are presented for biological parameter estimates of spangled emperor in the North sub-region (including Ningaloo Marine Park) and South sub-region of the Gascoyne. The reproductive ontogeny of spangled emperor in the North sub-region is described in detail from an analysis of microscopic characteristics of gonads and the categorisations of different stages of reproductive development, including pre-maturational sex change. The seasonality of reproduction is also described. The age, growth and mortality of spangled emperor in the North and South sub-regions is described, compared and contrasted and management implications discussed.

Outcomes for the sustainable management of fishing in the Ningaloo Marine Park include:

i. Recommendations to DoF managers on the sustainability of fishing demersal scalefish stocks, which will be used to determine the level and type of management response, including the setting of the sustainable level of total allowable catch.

ii. Data to inform the ELFsim Management Strategy Evaluation model (CSIRO), which will be used to evaluate, in simulation space, the effectiveness of sanctuary zones within the Ningaloo Marine Park. The ELFsim model (see abstract by R. Little, this proceedings) facilitates the combined input of different stakeholder groups (e.g., DEC, DoF, CSIRO) in the setting of management targets, against which the alternative management strategies (including alternative management plans for marine protected areas) are evaluated. Spangled emperor is the target species that is harvested in the model, and so the simulated population and harvest dynamics of this species is informed directly by results of this DoF research.

<u>References cited:</u>

Wise, B.S., St John, J. and Lenanton, R.C. (Editors) 2007. Spatial scales of exploitation among populations of demersal scalefish: implications for management. Part 1: Stock status of the key indicator species for the demersal scalefish fishery in the West Coast Bioregion. Final report to Fisheries Research and Development Corporation on Project No. 2003/052. Fisheries Research Report No. 163, Department of Fisheries, Western Australia, 130p.

Integration of science into Management – Exmouth Gulf Prawn Fishery

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The Exmouth Gulf prawn fishery is multi-species and regionally based worth around $10 million annually with currently a single operator and provides employment and returns to the local community. Over the last 10 years the fishery has evolved from being tightly legislated to now being based on a simple open and closing date with all interim measures through a flexible arrangement involving researchers, managers and the industry working co-operatively.

Sustainability is ensured through undertaking recruitment and spawning stock surveys and maintaining adequate breeding stocks through fishing to threshold catch rate levels and/or seasonal and spatial closures whilst the industry benefits from being able to optimise value of prawns based on market demands and prices. The ability to predict tiger prawn catches annually and understanding king prawn size structure and abundance for the year further assists industry to plan for the upcoming fishing season. In addition, a fleet restructure with guidance from the Fisheries Department has provided industry with higher a catch capacity per boat and reducing overall operating costs.

In addition to direct fishery management, consideration of impacts of fishing on the habitats has been addressed through implementation of bycatch reduction devices to reduce trawl bycatch by and by sampling bycatch diversity and abundance in trawled and non-trawled areas.

We will describe the process of annual stock assessments and how all benefit from real-time management strategies as well the science behind mitigation strategies for fishing impacts.

Magnitude and patterns of herbivory in Ningaloo Reef

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Within the marine environment, the highest levels of herbivory occur in tropical systems, where grazers play a key role in maintaining the resilience of coral reefs by reducing the cover of macroalgae, which can otherwise outcompete corals. Without herbivores to reduce algal cover, dramatic phase shifts from coral to algal-dominated systems have been observed throughout the world, causing catastrophic degradation and system-wide collapse. Understanding the quantitative nature of algal-herbivore interactions and the mechanisms that regulate herbivore feeding are thus essential for the successful management of coral reef systems. The overall aim of this project is to quantify the magnitude of herbivory and to characterise the patterns driving plant-herbivore interactions in Ningaloo Reef. Specifically, we are asking: (1) What primary producers are driving the grazing pathway in different habitats and regions?, (2) How does herbivore intensity vary spatially?, (3) What are the key species and functional groups of herbivores involved in macroalgal removal, and how much do individual species consume?, and (4) How does herbivory in Ningaloo compare to other coral reef systems at similar latitudes? Natural dietary markers (stable isotopes and fatty acids) are being used to determine the ultimate source of primary productivity and to characterise the grazing pathway in a range of habitats and regions within Ningaloo. Algal bioassays are being used to determine broad relative differences in herbivory among a cross section of the reef (lagoon, reef flat and outer reef habitats) and between different regions of Ningaloo. Differences in herbivory between habitats or regions are being correlated with herbivore abundance, benthic community structure, algal biomass and habitat rugosity. Remotely operated video cameras are being used to determine the relative contribution of individual herbivorous fish to the removal of transplanted algal bioassays, and the natural feeding rates and substrate selectivity of roving herbivorous fish is being determined in situ by following and filming individual fish from the most dominant species. Finally, a trans-continental comparison of herbivory between Ningaloo and the southern Great Barrier Reef has been undertaken. Remotely operated video cameras have been used to determine species-specific rates of macroalgal removal by herbivorous fish in a range of sites within each East-West region. In addition, herbivorous fish populations and algal biomass from three habitats and sites within each region (lagoon, reef flat and outer reef) have also been quantified. Outcomes from this project will provide detailed functional knowledge of the process of herbivory in Ningaloo Reef, including information on the distribution, abundance and ecosystem impact of individual species of herbivorous fish. Since these are key players that are able to prevent degradation in coral reefs, this information will be crucial in the development of management plans for the Ningaloo Marine Park.

Testing zone adequacy: Movement and habitat utilization of fishes in Ningaloo Marine Park

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Ningaloo Marine Park encompasses the majority of Ningaloo Reef, the largest fringing reef in Australia. There are 18 sanctuary zones comprising 34% of the marine park which are designed to protect representative habitat from human disturbance. These zones also provide refugia for exploited species, with research in Ningaloo Marine Park showing that the abundance and size of some species in sanctuary zones is higher than in comparable habitat adjacent to these zones.

The size, shape and range of habitats that a sanctuary zone covers as well as the biology and ecology of individual species will influence the degree to which sanctuary zones provide refugia to different species. A greater understanding of the movement patterns and habitat utilisation of a range of key teleost and elasmobranch species is therefore required to inform spatial management and any future decisions about the size, shape or location of sanctuary zones. Long term data on the habitat utilisation is also critically important in understanding the influence the movement and spatial distribution of species have on the composition of the ecosystem they inhabit. Movement of species in different habitats (e.g. reef slope, lagoon, rubble, sand and coral) are required to determine if fish display habitat-related variability in movement patterns, and to relate the intensity of key processes within different habitat types to fish movement and habitat utilization. These data can then be used to ensure that critical habitats are adequately protected, and that fish populations are not vulnerable to over-exploitation at these locations or during critical life history phases.

In order to gain a better understanding of movement patterns and habitat utilisation of fish and elasmobranchs within the marine park, the Ningaloo Reef Ecosystem Tracking Array (NRETA) was established in 2007 as part of the national Australian Acoustic Tracking and Monitoring System (AATAMS). NRETA consists of 104 acoustic receivers along the Ningaloo coastline and is Australia's largest array of acoustic receivers. The primary objective of NRETA is to determine the spatial and temporal habitat usage and movement of key reef species and the significance of these species to the trophic structure of reefs. An array of 50 receivers was installed around Mangrove Bay in November 2007, with eight additional receivers installed in May 2008. The receivers cover the intertidal lagoon, reef crest and reef slope habitats to a depth of 50 m covering an area of approximately 29 km^2.

Between November 2007 and January 2009, 214 teleosts from 17 species and 80 elasmobranchs from 10 species have been tagged with coded acoustic tags within the Mangrove Bay array. The acoustic tags have a battery life between 75 – 1200 days and an effective range of 200 – 600 m. Each time a tagged animal is within range of an acoustic receiver, the date, time and identification code of the tagged animal is recorded. Over time, these data build up a picture of the individual's movement patterns. The main teleost species tagged to date are: Spangled Emperor (n = 71), Yellow Tail Emperor (n = 37), Silver Drummer (n = 20), Black Wrasse (n = 19), Green Finned Parrotfish (n = 14), Gold Spotted Trevally (n = 13), Coral Trout and Coronation Trout (n = 11) and Rankin Cod (n = 7). For elasmobranchs the main species tagged are: Black Tip Reef Shark (n = 16), Nervous Shark (n = 11), Giant Shovelnose Ray (n = 10), Grey Reef Shark (n = 9) and Cowtail Stingray (n = 8).

Between November 2007 and January 2009, over 1 million detections of tagged animals have been recorded within the Mangrove Bay array. Insights from the data include indications of spawning aggregation sites for spangled emperor, schooling behaviour, high levels of site-fidelity in pelagic species and elasmobranchs, and multiple behavioural modes within species. We will present a summary of data collected to date and focus on the movement patterns and habitat utilization of spangled emperor *Lethrinus nebulosus* and silver drummer *Kyphosus sydneyanus* in relation to habitat-use and reproduction. We are in the process of developing a movement model at both an individual animal and species level. This model will use data from the tagged animals as well fine scale habitat data from aerial photography and bathymetry data to develop a predictive model of animal movement. The influence of variables such as season, time of day, daily wind strength and direction, daily wave height and direction and daily temperature will be investigated using data collected during the study period.

Loggerhead turtle nest predator dynamics on a mainland nesting beach in Cape Range National Park

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Nest predation by introduced European red foxes *(Vulpes vulpes)* has been identified as a key threatening process for endangered sea turtle populations in Australia. In fact, it has been suggested that ongoing nest predation by feral foxes may have contributed to the decline of Western Australian mainland nesting populations (Baldwin et al. 2003), as indicated by anecdotal evidence of fox predation on turtle nests and hatchlings in Coral Bay in the early 1990s.

This study aims to improve the understanding of factors affecting hatching success and in particular, assess levels of predation and predator dynamics at the mainland Loggerhead turtle (*Caretta caretta*) nesting beach in Cape Range National Park, to enable informed decisions to be made with regards to prioritising management actions. The research was conducted for two nesting seasons (2006/07 and 2007/08) and results show that predation by ghost crabs (*Ocypode spp*), varanid lizards (*Varanus giganteus*) and feral European red foxes considerably reduced survivorship from egg to hatchling. 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.

Surprisingly, ghost crabs were responsible for the majority of recorded predations. In addition, ghost crabs predated on turtle nests at all stages of incubation. In general, ghost crabs tended to burrow into nests earlier during the incubation period compared to foxes and varanid lizards. Ghost crabs are natural predators; however numbers of ghost crabs could have increased above normal levels due to tourism activities.

Further investigations will be necessary in future to assess fox control strategies at nesting beaches and to investigate if ghost crab numbers have increased due to anthropogenic factors.

Understanding Complex Systems through use of Simple (Qualitative) Models

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The Ningaloo coast of northwest Australia is recognized for its world-class natural values, its economic potential from tourism development, and the fragility of its marine and near-shore environment. A number of research projects are underway to support sustainable tourism development for Ningaloo Reef. These projects include application of sophisticated models of the hydrodynamics of the reef-lagoon system, and regional-level ecosystem and socio-economic models, with the aim of understanding how to conserve valuable assets. A need exists to provide general integration across the different research programs, and additionally to elicit stakeholder involvement, knowledge and understanding. This is especially important in linking potential threats to assets, where, in complex ecological and socio-economic systems, there is often a bewildering array of possible causal connections. Where these connections are centred across different research disciplines, or are embedded within the collective experience of multiple stakeholders, then providing a credible and transparent modelling framework is especially challenging. This challenge is being met, in part, through the application of qualitative modelling that attempts to provide a general description of the physical, ecological and socio-economic systems, as elicited from scientists and stakeholders alike. These models are based on the sign of the direct effects (i.e., +, -, 0) that describe relationships between system variables. These models are relatively simple to construct because they do not rely on quantification of model parameters; thus they can provide a rapid means to develop and test alternate model configurations, and understand how different model structures can affect model dynamics. Such models can be used to identify potential indicator variables and make predictions of how the system might respond to disturbances or management actions. We demonstrate how qualitative has been used to facilitate understanding between scientists and stakeholder, to progress research and monitoring programs.

Resilience and Destination Modelling: the Ningaloo Destination Modelling Process and Model Use

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Recent research into social-ecological systems (systems where social and economic practices and behaviours are closely integrated with the resources provided by ecological systems) has used the concept of resilience to highlight how particular styles of management can endanger the ecological resources on which it depends. Resilience, broadly defined, refers to the amount that an ecological or social system can change before it flips into a new mode of behaviour. In practice, ecological and social systems evolve together and are reliant on each other and need to be considered together as a single entity. In this presentation, we will be focussing on one aspect of resilience of tourism in the Ningaloo Coast region: adaptive capacity, or the ability of a tourism destination to cope with novel situations without losing options for the future. Adaptive capacity is important for both the ecological and social elements of a system. For instance, fish stocks could be reduced beyond the capacity to recover, or a sustained downturn in tourist numbers could lead to the loss of tourist operators and therefore the capacity of a destination to manage tourism. Both of these examples indicate the importance of managing a destination in such a way that it has the resources to recover from shocks. The goal of adaptive management research is to assist different groups and institutions to focus on managing the capacity of social-ecological systems to cope with, adapt to, and shape change. However, much research is often not effective at influencing how systems are managed. Tourism is particularly difficult as it involves a variety of sectors that provide services to tourists, and can impact entire communities.

In this paper, we discuss how destination modelling can contribute to adaptive capacity through exploring both the research project process and through the use of system dynamics modelling. First, we will discuss the importance of constructing the research process in a way that supports learning amongst groups that are affected by the system. We will then examine three factors identified in resilience research as being able to increase adaptive capacity and how they can contribute to managing tourism in the Ningaloo Coast region: understanding the dynamics of a system is a necessary component of sustainable management (Perrings, 2006); that basing present decisions on future conditions can reduce the severity of negative downturns in a human system (Gunderson & Holling, 2002); and that managing to protect the diversity of assets (both natural and social) increases a social-ecological systems ability to function over a range of both social and environmental conditions. Each of these features will be discussed with reference to modelling results and stakeholder workshops.

The value of recreation and management strategy evaluation

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Market-based transactions may be reflecting only a small portion of the value of a natural resource. This is particularly true for places like Ningaloo where recreation is a major component of the Park's uses. People derive benefits from visits to the Ningaloo over and above the expenses they incur in the process of getting there and staying there. These benefits are a reflection of the value that visitors attach to the 'experience' of recreating in the Park. As these values cannot be observed in market prices, they need to be measured indirectly. Over the last four decades, economists have developed methods for estimating these 'non-market' values. And non-market value estimates are now widely used in environmental impact assessments, cost benefit analyses of projects and litigation.

In balancing conflicting demands, resource managers and policy makers need to take non-market values into account, along with the economic benefits generated by tourism and commercial activities impacting on the resource. The Management Strategy Evaluation (MSE) model of the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster includes models that simulate non-market values relating to fishing and non-fishing recreation. The models, known as Random Utility Models (RUMs), have been constructed using survey data collected from visitors to Ningaloo and from recreational fishers around the state.

The recreational fishing models are state-wide, covering 48 fishing sites in Western Australia. Four of these sites are in the Ningaloo Region. The non-fishing RUM models are fitted with data from all Ningaloo sites which are grouped into 12 sites.

These models contribute to management strategy evaluation in two ways:

1) As behavioural models, the RUMs predict the distribution or redistribution of recreational site choices. These changes could be the result of events that are under the control of resource managers or other external events.
2) The models also provide non-market value change estimates that occur as a result of changes in the resource condition (fish stocks, site quality, accessibility, etc.) or its management. What is the value of additional stock of fish at a particular site? What is the value that society derives from the existence of a particular site?

Resource managers and other stakeholders are able to use these tools to facilitate dialogue and to generate value estimates that can be sued as input into policy evaluation.

Testing system understanding across different complex management problems

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How transferable is the understanding of system dynamics across different complex problems typically encountered in the management of natural resources? That is, if we gain experience in managing a complex system under certain external and internal pressures, can we expect to be well prepared to transfer this expertise to the management of a system experiencing completely different pressures? Or to another system altogether?

Answering these questions has important and direct implications for Management Strategy Evaluation: it can provide experimental evidence of its effectiveness or otherwise, it may inform us on how to make best use of the numerical models and may eventually lead to the development of methods to provide managers with the skill needed to address a range of problems common to system dynamics.

In the Ningaloo Research Program Management Strategy Evaluation is cast within the framework of a number of studies which underlie and contribute to the development of large numerical models which are then used to condense the problem knowledge (and uncertainty) and are then employed in an exploratory fashion to devise possible management strategies and evaluate their likely outcome via virtual experiments.

Among others, there is one assumption and one expectation behind this approach: the assumption is that modelling is useful to improve system understanding; the expectation is that by carrying out these kinds of exercises on different problems our understanding broadens and our capacity to transfer the knowledge to related, but different, problems improves.

The purpose of the project is to generate some evidence for or against the above claims. We have set up a team to work on this, comprising two modellers with experience in complex system science, a psychologist, a sociologists and a student with masters in both Marine and Social and Political Sciences. We aim to use tools ranging from numerical modelling, to psychological questionnaires and description and analysis of mental cognitive models to address these questions.

The first step in our project involves a set of experiments, carried out in collaboration with the Australian Defence Science and Technology Organisation (DSTO), in which system understanding and cognitive styles will be assessed on subjects ranging from undergraduate students in Environmental Science to experienced military officers. We expect the results of the experiments to provide insights into how subjects deal with complex problems and how they use complex computer models to address them.

In this presentation we will summarise the relatively sparse and conflicting literature on the subject, describe the planned experiments and discuss possible project developments.

Ningaloo Deeper Water Biodiversity: a WAMSI collaboration in progress

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The majority of the Ningaloo Marine Park lies seawards of the reef crest. There has been very little information about habitats and biota in the deeper areas, especially beyond 30m where scientific diving is rarely conducted.. A collaborative project, led by AIMS but involving Curtin University, UWA and the WA Museum, has sought to discover and describe the major habitat types, establish a baseline biodiversity inventory and improve broad scale understanding of bathymetry and geomorphology throughout these offshore areas. A majority of the offshore marine park is <100m deep and this has been the nominal limit of survey in the current study. A variety of sampling tools have been used, including towed video and still camera systems for habitat mapping, baited video for fish surveys, benthic sleds and grabs for collection of biological samples and sediments, together with single and multibeam acoustics for bathymetric survey.

There are clear offshore gradients and transitions between different seabed types and associated biological communities. In particular areas, hard substrates such as low relief rocky ledges, support diverse and abundant filter feeding communities, although sand and rubble zones are the most extensive habitats observed. In terms of the larger sessile biota, these rocky areas covered in sponge gardens may represent biodiversity hotspots in the offshore component of the Park. They have been observed in both the northern, central and southern areas of the Park but are patchy in distribution and vary in species composition. Their representation in the current offshore sanctuary zones will be subject to future analysis.

The northern-most end of the Park has a moderate width shelf which is gently sloping, but it narrows to the south and runs parallel to the coast. At Mandu the shelf is narrow (~10km) gently sloping, but with a marked change in gradient at the shelf break(120-170m) , dropping steeply to depths of 1000 m within only 20km offshore. This general geomorphology extends further south, but at Pt Cloates the inner shelf, between the fore reef and depths of approximately 60m, also has an extensive complex topography of ridges, small lumps and pinnacles.South of Point Cloates there is a marked transition in bathymetry with a gentler and increasingly wider shelf to Red Bluff, where the outer Park boundary only reaches depths of 50-60m.

Corals, while very important in the immediate fore-reef slope area, are not a major component offshore, particularly beyond depths of 40-45m. The presence of corals on hard substrates at the southern end of the park was less predictable, even in depths of 30m, suggesting some difference in community level ecology between the northern and southern sectors. Excepting where corals dominate, hard substrates throughout Ningaloo Marine Park are dominated by filter feeders, particularly sponges. A total of 155 taxa of dominant sponges, 227 taxa of echinoderms, and 236 mollusc taxa have been identified to date. Of the 155 sponge taxa identified, only 31 could be given a known species name. The rest of the species were only able to be assigned to a genus and given a species number. These are most likely poorly known species described in old taxonomic literature or are new to science.

An initial survey of deeper water fish communities, identified 319 species of finfish from 54 families The same habitats at different depths were often associated with significantly different fish fauna. Coral reefs in 15-30 m supported a different fish assemblage to those in 30-50 m. Fish assemblages in rhodolith habitat in 30-50 m were significantly different to those at 50-70 m. Fish assemblages associated with sand habitat differed between all depth ranges with the exception of 30-50 and 50-70 m depths. Likewise, fish fauna found in sponge habitat at 90+ m were different to those found at both 50-70 and 70-90 m depths. Rhodolith habitat supported similar fish assemblages across all depth ranges with the exception of those found in the midshelf depths of 30-50-70 m. Sponge and sand habitat supported similar fish assemblages between 50-70-90 m depths. A major whole marine park offshore survey of fish is underway during April-May 2009. Further analysis of relative abundance and size frequency will be carried out and integrated into a comprehensive synthesis report due in 2010.

It is clear that even though this study has only focussed on macro biota, some significant high diversity, high biomass areas existing in the deeper waters and those are likely to contribute significantly to the overall biodiversity values, by national and international standards, associated with Ningaloo Marine Park. It also is clear that there are strong functional linkages between the deeper offshore waters of the Marine Park and the adjacent, more commonly encountered, shallow reefs and lagoons.

Mapping the marine benthic habitats of Ningaloo Reef lagoon

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Effective management and monitoring of large marine protected areas requires detailed baseline data on distribution of benthic habitats (as a surrogate for marine biodiversity). Large areas with complex bathymetry and very clear waters such as the Ningaloo Marine Park (NMP) naturally lend themselves to the application of optical remote sensing as a means of gathering data on substrates and depth. An airborne hyperspectral remote sensing mission of the NMP was flown in April 2006 over 10 days to acquire data over 3400 km^2, at 3.5 m pixel resolution, using 125 bands in the visible to near infrared range of the electromagnetic spectrum and 21 bands sensing over the water areas. Hyperspectral data have been corrected for the influences of the atmosphere, air-water interface, water depth and water constituents (phytoplankton, suspended matter and Gelbstoff absorption). These images have now been processed to retrieve bathymetry over shallow lagoons (0-20 m depth) in order to create slope and aspect images to assist in understanding the distribution of benthic cover types. Further, combined depth, aspect and slope images can aid in designing stratified sampling schemes for detailed biodiversity studies. Visible bands from the sensor have been used to detect and map the distribution of a number of cover forming benthic components such as sand, limestone pavement, rubble, macroalgae and different coral types/growth forms such as tabular, branching, digitate and soft corals. Ten field trips have been completed to collect underwater spectra of dominant, cover forming benthic components and to acquire high resolution benthic cover data for training and validation of the final benthic cover maps. A quadrat, transect and single point sampling approach has been used to collect nearly 3,500 field validation points. Data products generated in this project include the distribution of the major benthic cover types as well as per-class probability maps. Hyperspectral data for the 1-2 km coastal strip adjacent to the NMP has also enabled mapping of 4WD tracks, vegetation cover and bare areas based on their spectral properties.

Growth History, Geomorphology, Surficial Sediments and Habitats of the Ningaloo Reef

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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 (last 2 Ma) foundations and ancestral topography played a major role in the establishment of Holocene (last 10 ka) reef development and are the primary physical controls on contemporary geomorphology and habitats. There is a strong transition from photozoan-reef to heterozoan-carbonate ramp producers across the Ningaloo shelf. Encrusting coralline algae, coral, macroalgae, turf algae and seagrass habitats thrive across geomorphic zones of the back-reef. Preliminary analysis of coral community structure and sedimentary facies 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, 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 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.

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. Geo-physical 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 role as 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 is being established. The relationship between reef growth and sea-level fluctuations during the Holocene will provide a basis for assessment of the future impact of climate and sea-level change on the reef and coastal ecosystems. Some of the key findings of the study are summarised below.

Growth History

- The Pleistocene and Holocene growth history and chronology has been determined for reefs on the western and eastern sides of the Cape Range.
- On the eastern Ningaloo Reef at the marina site:
  - Maximum Holocene reef thickness is 5 m.
  - Onset age is 7.9 ka with termination of the reef at 5.8 ka indicating a drowned '**give up**' reef.
  - Distinct reef facies have been identified in the Holocene (MIS1) and Last Interglacial (LI; 125ka; MIS5e) reef units.
  - Reef development was influenced by antecedent topography, rising sea-

  - levels and changing environmental conditions.
  - An underlying marine unit (MIS7?) was identified, deposited during restricted hypersaline marine conditions.
- On the western Ningaloo Reef (northern part):
  - Maximum Holocene reef flat thickness is 8 m and the reef has grown to sea-level characterising it as a '**catch up**' reef.
  - Significant later reef development occurred compared to the eastern Ningaloo Reef.
  - Active growth occurred post the Holocene highstand (SL of +2m at 6,000 years BP)

- The relationship between reef growth and sea-level fluctuations during the Holocene has provided a basis for assessment of the impact of climate and sea-level change on the reef and coastal ecosystems.

Inshore Geomorphology, Sediments and Habitats

- Geomorphology of the reef has been mapped and characterised.
- The LI reef provided a template for Holocene growth and there is a strong relict signature in reef morphology (foundations, sea-level fluctuations, karst, backstepping reef construction).
- Geomorphology is a major control on broadscale habitat distribution.
- Sedimentary assemblages consist of photozoan-reef (warm water/low nutrient) producers.
- Fine-scale reef habitats and coral communities have been mapped and characterised in the northern Ningaloo Reef, and their geomorphic and environmental controls identified.
- Generation of GIS layers and maps for: bathymetry, seabed texture, geomorphology, sedimentary environments and habitats is continuing.

Offshore Geomorphology, Sediments and Habitats

- Broadscale geomorphology has been described for the entire Marine Park.
- The narrow continental margin with distinct geomorphic zonation across the shelf was generated by changing sea-levels. Relict and modern sedimentary bedforms have been identified.
- A number of geomorphic features and sedimentary environments across the shelf, that are important for habitat development, have been mapped and identified.
- Sedimentary facies have been described and mapped. Distinct facies zonations occur both across the shelf and latitudinally.
- Sediments are almost entirely biogenic consisting of older relict and reworked grains with modern skeletal fragments, with dominance of heterozoan-carbonate ramp (cold water/high nutrient) producers.
- Sediments have assumed the character of the benthos and are a proxy for the habitats that produced them.
- Generation of GIS layers and maps for bathymetry, seabed texture, geomorphology, sedimentary environments and habitats is continuing.

Characterisation and modelling of oceanographic processes at Ningaloo Reef

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Like all coral reefs, the ecology of the Ningaloo Reef system is closely linked to water motion, which transports and disperses vital materials such as nutrients and larvae. As a result, successful management of this system ultimately requires a detailed quantitative understanding of the dominant hydrodynamic processes that operate within this system (e.g., waves, currents and water level variability) and its relationship to broader oceanographic processes in the region such as the Leeuwin and Ningaloo Current. Relative to other nearshore systems such as beaches that have been well-studied, the nearshore dynamics controlling the spatial and temporal variability of wave and current energy in coral reef systems is still poorly understood. This because nearshore analytical theories and numerical models have largely been developed and tested on beaches, which have very different morphological characteristics to coral reefs (e.g. bathymetry and bottom roughness properties).

The response of the water circulation off Ningaloo Reef (the largest fringing coral reef in Australia) to wave, wind, and tidal forcing was studied using field data and the output from a coupled numerical circulation – wave model. A six-week field experiment measuring waves, currents, and water levels was conducted during April to May 2006. This study focused on the flow dynamics within a representative reef – channel circulation cell (one of hundreds that comprise the overall system). The results showed that wave forcing was the dominant mechanism driving the water circulation off Ningaloo Reef, with lagoonal flushing times of five to eight hours under typical offshore wave conditions. Cross-reef wave-driven currents, however, were weaker (~0.1–0.2 m/s) than expected from existing one-dimensional analytical models of reef circulation; this was likely due to the presence of the wave set-up inside the shallow lagoon, which is neglected in the analytical approaches. Preliminary results from the three-dimensional numerical model will be presented.

The Biological Oceanography of Ningaloo Reef

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Despite global threats, factors controlling coral reef productivity remain poorly understood. We show that coral reefs are highly dependent on the production and supply of nutrients, particularly nitrogen, from the surrounding ocean. This has significant implications for the ongoing health of coral reef ecosystems. We identify wave action and the dynamics of regional currents as important factors determining plankton supply to the reef, which may be critical in driving reef nutrition. For example, plant plankton (phytoplankton) were taken up by reef organisms from water forced over the reef by wave-driven flows. These uptake rates ranged from 4 – 8 mg chl a m-2 d-1, with uptake coefficients (S) ranging from 9 – 21 m d-1. Phytoplankton uptake appeared to be mass-transfer limited with preferential removal of picoplankton (small bacterial cells). Our numbers suggest that the reef takes up nitrogen-rich organisms quite rapidly, causing a flux into reef organisms of 2 – 5 mmol N m-2 day-1 from phytoplankton alone. This is on the order of typical dissolved uptake for a reef, confirming the importance of planktonic feeding in reef nitrogen budgets. When we consider the scale at which Ningaloo Reef filters water delivered to it from the ocean in different seasons, we estimate that coral reef organisms are likely to require 1180 km2 d-1 of Leeuwin Current water for their phytoplankton supply in autumn and winter, compared to only 180 km2 d-1 of nitrogen rich waters of the wind-driven upwelling current, the Ningaloo Current. A functional dependence on ocean productivity by reef organisms increases the potential scale at which human- and climatically-induced changes may affect a reef. The potential for such changes to alter the quantity or quality of ocean-sourced planktonic food and thereby affect reef health requires further consideration.

Long term trends in the Leeuwin Current and implications for marine ecosystems

Ming Feng and Evan Weller

CSIRO Wealth from Oceans National Research Flagship, Marine and Atmospheric Research, Floreat, WA

The volume and heat transports of the Leeuwin Current have a strong influence marine environment and fisheries recruitments off the west coast of Australia. The Leeuwin Current and its eddy field also play a significant role in retention of fish larvae and alongshore connectivity on the continental shelf – the shelf region off Ningaloo tends to have very low local retention.

Since the climate regime shift in mid-1970s, there have been more frequent El Nino events, which drives a weaker Leeuwin Current. The regime shift pattern is similar to the pattern of weakening trade winds induced by enhanced greenhouse gasses in the atmosphere. Subsurface cooling are observed off the northwest and west coasts, as a result of the weakening of the trade winds in the Pacific, and different numerical model simulations show 0-30% declining trend in the Leeuwin Current transport, as well as a shallowing trend of the thermocline. A moderate warming trend has been observed off Ningaloo, and the combination of surface warming and subsurface cooling may have resulted in a sharper thermocline in the offshore region, which may limit the vertical turbulent flux of deep nutrients to the surface euphotic zone.

CSIRO Mk3.5 climate model projection suggests that sea surface temperature off Ningaloo will continue to warm by nearly 1℃ in 2030's and by more than 2℃ in 2090's, due to the increase of both solar radiation and downward long-wave radiation, under the medium greenhouse gasses emission scenario. The Mk3.5 model projects a further slowing down of the Leeuwin Current, while a statistical modelling based on global sea level rising trend suggests that the strength of the Leeuwin Current may increase under future climate, likely due to the increasing hydrological cycle in the earth system. These analyses will be synthesised using dynamic downscaling of the Mk3.5 climate projection. The Mk3.5 model also projects a strengthening of the summer alongshore winds off Ningaloo, the impact of which on coastal upwelling will be assessed using the downscale modelling.

Establishing a long term marine monitoring programme for ecological and social assets in Western Australia

Kim Friedman

Marine Monitoring Unit, Marine Science Program, Department of Environment and Conservation, Kensington, WA

DEC is in the development and early implementation phase of a coordinated state-wide marine monitoring program. The focus of the Western Australian Marine Monitoring Program (WAMMP) will be on assessing the effectiveness of DEC's conservation and management programs for the State system of MPAs and threatened marine fauna. The Condition-Pressure-Response (CPR) model, within an active adaptive management framework, provides the conceptual framework for the WAMMP. The implementation model is primarily a partnership approach between the Marine Monitoring Unit (MMU) of the Marine Science Program and DEC's regions and specialist branches. Importantly, assistance from external science groups (e.g. universities AIMS, CSIRO, etc) will be sought on a collaborative (preferably), and/or fee-for-service basis.

The establishment phase of WAMMP has centred on the collation and review of past and present data that describes values listed in marine park management plans. These reviews highlight the status, recognised pressures and management actions related to ecological and social values of interest and guide the development and implementation of standard operating procedures to monitor these values over time. This paper outlines WAMMP progress to date and suggests ways that other agencies can engage in the process of monitoring and supplying information relevant for management of ecological and social assets in Western Australia.

Knowledge and the role of networks-enhancing the effects of models in assisting decision making

Peta L Dzidic, Jeff M Dambacher and Geoff J Syme

CSIRO Wealth from Oceans National Research Flagship, Floreat, WA

One of the significant activities in the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster is the development of models of various types that will serve as a major integrating output. While there is an "all encompassing" model (InVitro) there are also activities to incorporate qualitative modelling and "user friendly" modelling of components.

The intent is that these efforts will result in informed decision makers and managers who will have tools that they will regularly use to reach intelligent decisions that enable them to manage the uncertainties associated with what is a complex socio-ecological system. To help ensure that adoption happens, CSIRO's Wealth from Oceans Flagship created a small "client outreach" project, the purpose of which was to monitor the decision support needs of government and to help match these with the outcomes of the modelling.

This paper presents data from social network analysis in defining critical roles in both the decision making system and the research program as a whole. It discusses how they may be connected to ensure efficient and effective communication between scientists, modellers and decision makers.

Surfing the Reef: The case for visualisation in natural resource management

Dr. Stuart Minchin
Research Director, Environmental Observation and Landscape Science, CSIRO Land and Water, Canberra, ACT

This presentation will focus on the benefits of advanced visualisation in engaging the broader community in the management of precious natural assets such as Ningaloo Reef. The talk will describe some of the advances made in the visualisation of water resource information to support the water market and the role of platform technologies such as Google Earth in delivering visualisations to stakeholders and the public at large.

Translating research into practice: working to build adaptive institutions for sustainable tourism in Western Australia's Ningaloo Region

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In 2001 the State Government recommended the nomination of the Ningaloo Marine Park for World Heritage listing. The area is now widely marketed as a one of Western Australia's premier tourism destinations and given the area's unique attractions visitor numbers are ever increasing. However, tourism development to date has been somewhat '*ad hoc'* and the social, ecological and economic sustainability of tourism in the area is being challenged on numerous fronts by over-burdened infrastructure, waste generation, high impact developments, effects on visitor experience, site erosion, fishing pressure, accommodation shortages and crime. In response to these challenges, the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster (NCC) has brought together scientists and expertise from a range of disciplines with the goal of describing, understanding and modelling the processes of human interaction with Ningaloo Reef.

The uptake of sustainable management options - moving from research to practice – however, depends on the adaptive capacity of the institutions responsible for governing tourism activities in the Ningaloo area. Adaptive capacity in this case can be framed as the collective ability and willingness of institutions to respond to NCC's data and modelling results, and can be assessed by the quality of decisions made *and* implemented by institutions in terms of their impact on the region's social and ecological sustainability. Increasing institutional adaptiveness means moving away from narrow resource-use issues and focusing instead on building system-wide resilience across numerous social and ecosystem scales. This requires eliciting multiple perspectives and sources of knowledge from diverse stakeholders as a way of dealing with the subjectiveness and uncertainty of complex science-related issues. Adaptive institutions must also be flexible, capable of self-organization and willing to embrace change and experiment.

However, the literature indicates that despite careful research, modelling and planning, resource management, recommendations in complex social and ecological systems, such as those being proposed for tourism in Ningaloo, often fail to deliver on the ground. Since the 1970s, many writers have challenged the notion that managerial decision-making is rational or logical. Rather, decisions are based on complex political pressures and contextual dynamics, often using incomplete information. Often there is a lack of political will to implement necessary change. For these reasons, command-and-control oriented centralized governments with political links to legislature and industry are prone to problems and making large mistakes. In addition, continued belief in the value neutrality of science, and failure to accept the inherent social and ecological uncertainty pervading resource management issues, creates a sharp division between science and values. This increases miscommunication and prevents true learning as the flow of information between scientists, managers and other stakeholders is blocked.

The creation of adaptive institutions is also challenged by institutional inertia caused by uncertainty, self interest of individuals and organizations, greed and career concerns among scientists, and powerful vested interests that exploit and exaggerate uncertainty and gaps in scientific knowledge to maintain the status quo. Inertia is further engendered by resistance from researchers and managers who fear failure, increased transparency, and political risks. In addition, institutional inertia can be caused by the high cost of information gathering and monitoring, insufficient financial resources, unskilled human resources, poor leadership and focus on perfecting modelling tools rather than field testing them.

Insensitivity to environmental feedback also impedes the adaptive capacity of institutions. Larger, centralized institutions are often more insensitive to negative environmental feedback than are local institutions. Global tightening of interdependencies between local resource users and regional, national and international communities is further weakening feedback loops to the ecosystem. This is aggravated by support from socio-economic infrastructure (e.g. loans, subsidies, insurance, aid) at different scales, which impedes socio-ecological learning by making it possible to maintain business as usual during crises.

Problems with communication and participatory processes can also reduce adaptive capacity. It is difficult to reconcile the technical specialized understanding of researchers and management agencies with the place-based knowledge of local communities. When managers and scientists act superior, local people get angry at what they perceive to be arbitrary scientific judgements and major communication breakdown and loss of trust occurs. Loss of trust can lead to erosion of social resilience, and the polarization that arises between stakeholders may itself inhibit ability to respond to ecosystem feedback as competing interests, each with virtual veto power, stifle innovation. Local horizontal power structures typically work to reinforce existing inequalities and the status quo within communities, and face-to-face interactions in participatory processes are subject to intimidation or coercion.

Many of these barriers are similar to those faced by businesses trying to improve their own learning and response capabilities, and are linked to the ‘homeostatic’ nature of all organizations/institutions. Focusing on the social processes at work is therefore critical to building adaptive institutions. As such, a new research project is underway in the Ningaloo area, aiming to engage researchers, policy makers, resource managers and other stakeholders in a bid to overcome these barriers, and to establish adaptive institutional arrangements for synthesizing and acting on data generated by research/modelling efforts in the region (thereby encouraging socially and ecologically sustainable tourism in the long term.

The study hypothesizes that engaging stakeholders in a deliberative and transformative co-learning approach will increase the likelihood that adaptive institutional arrangements are developed. The approach will specifically involve a combination of transformative participatory decision-making processes, organizational change management strategies, and the eight elements of Learning Tourism Destinations. An action research methodology will be applied, using social ecology systems theory and a collective learning and collaborative planning framework.

POSTERS AND ADDITIONAL

ABSTRACTS

Development and demise of a fringing coral reef during changing sea-level and environment in the Holocene, eastern Ningaloo Reef, Western Australia

Emily J Twiggs and Lindsay B Collins

Curtin University of Technology, Perth, WA

One of the most important questions facing marine scientists is whether coral reefs can respond to future sea-level increases and environmental change. Fossil reefs are an important archive of the response of reefs to these changes, and provide analogues for modern reef response to climate change impacts. Western Australia has been described as perhaps the best natural laboratory for studying the effect of climate change on shallow water carbonates. Modern and late-Pleistocene coral reef communities, exposed along the coastline, provide unique opportunities to investigate the impact of climate change on coral growth. One such example is the Ningaloo Reef, a 300 km fringing to barrier reef in northwest WA. The reef wraps around the North West Cape and into the Exmouth Gulf embayment becoming increasingly incipient at its northeastern limit at latitude 22˚C. The Exmouth Gulf is a shallow and turbid inverse estuarine system which occurs within a low relief, arid and tectonically stable region. The Gulf has a highly weathered and dissected catchment, with inputs of terrestrial material to the coastal zone during cyclone and storm activity.

Sixteen core sections from the Exmouth boat marina were used to characterise the development of the Holocene reef. Cores were logged to define the overall stratigraphy of major reef units, and framework and detrital facies were classified based on the dominant coral growth form and detrital components. Nineteen U-Series TIMS dates confirmed the nature of the Pleistocene foundation and its influence on Holocene development, the timing of reef initiation and accumulation, and reef facies associations.

Three calcretised Pleistocene units were identified including: the Last Interglacial MIS 5e reef which directly underlies the Holocene; a mid-Pleistocene (MIS 7?) bioclastic conglomerate unit; and a Pleistocene alluvial fanglomerate. The Holocene veneered the Last Interglacial deposits and mimicked the antecedent topography throughout its development, forming thickness of up to ~5.3 m. Eight Holocene reef facies were identified including both reef framework facies (in order of dominance): (1) domal coral framestone; (2) arborescent coral framestone; (3) tabulate coral framestone and (4) encrusting coral framestone; and detrital facies including: (5) carbonate sand; (6) skeletal rubble and (7) alluvial mud. Distinct patterns in facies associations occur both vertically and laterally, reflecting changing environmental conditions during the Holocene. Reliable U-series Holocene dates ranged from 7929 ± 318 to 5800 ± 76 yrs BP. Vertical accretion rates ranged from 9.88 mm/yr to 1.46 mm/yr with an average of 4.11 mm/yr. The highest rate of accretion and thickest accumulation occurred on the most seaward and deepest cores, composed of massive coral framestone and coralline algal crusts. Reef accretion curves indicate an initial rapid phase with a trend of slowing accretion at around 7000 yrs BP.

The data were compared to the WA sea-level curve to understand potential reasons for patterns in Holocene reef development and its ultimate demise. There was a change during the mid-Holocene highstand from conditions favourable for reef accretion to conditions detrimental to accretion. Five stages of reef development have been recognised including: (A) Initiation 'start-up' from 7900-7500 yrs BP; (B) Rapid growth 'catch-up' and backstep from 7500-7000 yrs BP; (C) rapid growth 'catch-up' from 7000-6500 yrs BP; (D) Reef decline 'give-up' 6500-5800; and (E) Detrital build-up from 5800 to present. The reef's demise probably involved a combination of factors including response to increasing sea-level during the Holocene transgression, burial by terrestrial sediment input, increased turbidity and decline in water quality, and groundwater influx to the system with increased nutrient supply.

Ningaloo Research Day for Students

30 March 2009

CSIRO Centre for Environment

and Life Sciences

Floreat, Western Australia

Student Presentation Abstracts

The role of oceanographic processes in the trophic ecology of Ningaloo Reef

Alex Wyatt

PhD Student; University of Western Australia, Crawley, WA

While recycling of nutrients plays a key role in coral reef food webs, it is increasingly apparent that reefs may be highly dependent on the production, supply and incorporation of particulate nutrients from the ocean (plankton), which is controlled by processes over a variety of spatial scales.

At the regional scale, plankton production available to reef consumers may be controlled by oceanographic processes. For instance, seasonal upwelling at Ningaloo Reef, Western Australia leads to 10-fold increases in nitrate concentrations and over doubling of primary production in adjacent waters. We explore the implications of upwelling for temporal and spatial patterns in reef benthos using synoptic stable isotope data. Scaling phytoplankton uptake we show that Ningaloo may be linked to an area of ocean on the order of 1000 – 10,000 km^2 during upwelling and non-upwelling periods, respectively.

At the reef scale, wave-pumping over the reef flat drives plankton supply, with our data suggesting that uptake of phytoplankton alone represents a nitrogen flux to the reef up to an order of magnitude higher than typically reported for dissolved nitrogen.

At the organism scale, there is increasing interested in the role that plankton feeding plays in energy budgets, calcification and resilience to stressors. Stable isotope and fatty acid biomarkers are used to examine species-level plankton uptake, which we suggest may have implications for maintenance of reef biodiversity.

The process level understanding of reef-ocean linkages presented has significant implications for understanding reef function, as well as the response of reefs to global changes that will alter not only reefs themselves but also the oceanographic systems to which they are intrinsically linked.

Mapping Geomorphology and Sedimentary Environments for Conserving Marine Biodiversity of the Ningaloo Marine Park

Emily J Twiggs and Lindsay B Collins

PhD student, Curtin University of Technology, Perth, WA

This research is investigating Ningaloo Reef and the adjacent shelf, particularly evolutionary characteristics significant to the conservation of marine biodiversity. It forms part of WAMSI Ningaloo Research Program Project 3.4, covering the following research areas:

- Late Quaternary reef growth and development.
- Contemporary reef geomorphology and influence on habitat and coral community zonation.
- **Geomorphology, sedimentary environments and habitats of the continental shelf**.
- Carbonate sedimentology and broadscale geomorphology of the entire Marine Park.

This poster focuses on the deeper offshore waters in the northern Ningaloo region. High-resolution multibeam bathymetry and backscatter datasets, combined with towed-video transects, sediment grabs and benthic sled sampling, provides a fresh insight into the: detailed morphology and distribution of submerged reefs, platforms and sedimentary bedforms; distribution and nature of surficial sediments and their carbonate assemblages; role of geomorphology and substrates in shaping modern habitats and communities; modern oceanographic processes, and evolution of the shelf in response to fluctuating Late Quaternary sea-levels.

There is a strong association between geomorphology and benthic habitats with communities taking advantage of the availability of Pleistocene substrates. The hard bottom is composed of a 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. At the transition between the base of the slope and the inner shelf relict reef platform, reef rubble and rhodoliths supply the hard substrate for a diverse community dominated by sponges, crinoids, turf algae, soft corals (gorgonians, sea whips), bryozoans and *Halimeda*. On the inner-mid shelf submarine fans, formed from the offshore flushing of lagoon sediments through reef passes, complicate this pattern locally. Extensive linear ribbon dunes and scours and ‘large-very large’ bedforms on the mid to outer shelf, indicate a complex interaction of lagoonal currents, the northeast flowing Ningaloo and southerly Leeuwin Current systems. Communities are patchy in these regions with higher abundance associated with exposed substrates. Below wave-dominated processes, bioturbation is evident from echinoderm feeding traces, polychaetes and burrowing fish, and a diverse infauna has reworked the sediments to build mounds and burrows. Fields of large gravel mounds occur in depths of ~95 m and may indicate conduits to coastal groundwater and paleo-channel sites. A number of ridges and pinnacles have been identified at various depths with prominent and extensive systems on the mid-outer shelf (~70-125 m). These features are likely to represent drowned backstepping reef growth and paleo-shoreline erosion, reflecting a complex history during lower sea-levels. The Last Glacial (~20 ka) shoreline has been identified at the 125 m depth contour. Ridges are colonised by high cover of exotic sponge, gorgonian and bryozoan ‘gardens’ and diversity is particularly high in areas adjacent to continental slope canyons which bring nutrient rich, cold-water upwelling to the shelf edge.

Sediments are almost wholly biogenic in origin consisting of older relict and reworked grains mixed with modern skeletal fragments. There is a strong transition across the shelf from photozoan-reef (warm water/low nutrient) to heterozoan-carbonate ramp (cold water/high nutrient) producers. Depth consistent sediment facies have been recognized across the shelf based on component composition and grain size.

Production and transport of particulate matter in a regional current system

Cecile Rousseaux

PhD student; University of Western Australia, Crawley, WA

Recent studies have suggested that reefs may rely on importation of particulate matter from the adjacent ocean to sustain their high productivity. Here we examine cross-shelf gradients and transport of particulate organic matter in the Leeuwin Current system adjacent to Ningaloo Reef, Western Australia. Particulate matter, nutrient uptake rates and phytoplankton abundance and diversity (based on HPLC) were sampled in May and November 2008 along an 18km-transect running from the Ningaloo reef slope to the 500 m isobath. Phytoplankton concentration was much higher in May (~1 µg/L) than in November 2008 (~0.2 µg/L). In May 08 the phytoplankton community was dominated by diatoms with 10X greater concentration offshore (0.182 µg fucoxanthin/l) than close to the reef (0.02 µg fucoxanthin/l). This onshore-offshore gradient was still observed in November 2008 but the chlorophyll maximum was moved to ~2km off the reef. We also observed f-ratios of ~0.5 which is the highest values that have been observed in this region. This would suggest that new production peaks in autumn due to Leeuwin Current acceleration and not in summer during the upwelling season as expected.

The Policy Relevance of Choice Modelling: an application to Ningaloo & Capes Marine Parks

Abbie McCartney

PhD Student, University of Western Australia, Crawley, WA

This study applies the economic Choice Modelling (CM) technique to the Ningaloo Marine Park and proposed Ngari 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 ecological 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.

Spatial and temporal patterns of recreational use by visitors to the Ningaloo Marine Park

Claire Smallwood

PhD Student; Murdoch University, Murdoch, WA

Understanding the patterns of recreational usage which occur in multiple-use marine parks are essential for conservation and management. However, the collection of such spatial and temporal information at fine-scale resolution is rarely undertaken. A project to map the human usage within the Ningaloo Marine Park (NMP) is currently underway with geo-referenced aerial and land-based coastal surveys as well as face-to-face interviews with recreational participants conducted throughout 2007. These surveys were undertaken along the entire 300 km length of the NMP and showed that snorkelling, fishing, diving, surfing as well as charter tours for coral viewing and manta rays were some of the most popular activities undertaken by visitors. Mapping of the spatial and temporal patterns of the recreational activities has quantified the clear seasonality in usage with greater abundance and dispersion of people using the NMP during the peak winter months. As this study has comprehensively mapped the location of recreational activities along both the shoreline and in the lagoon environment of the NMP, factors that contribute to distribution patterns (coastal access points, infrastructure, demographics of visitors etc.) can be examined. In addition, travel networks used by visitors throughout the NMP to undertake shore and boat-based recreation have been identified and demonstrate the highly clustered and node-focused nature of visitor use. A clear understanding of both the distribution and connectivity patterns of visitors using the NMP should allow managers to focus their attention and resources in appropriate locations which may be exposed to increased pressure from recreational activities.

Spatial and temporal variation in fish assemblages within and adjacent two coral reef marine protected areas.

Ben Fitzpatrick[1], Euan Harvey[1], Russ Babcock[2] and Emily Twiggs[3]

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[3] Curtin University of Technology, WA

PhD Student; University of Western Australia, Crawley, WA

We describe patterns in the abundance of fish assemblages in relation to finescale biophysical habitat and summer and winter seasons over two years at two protected and adjacent fished locations at Ningaloo Reef in North Western Australia. We used benthic video transects combined with stereo-Diver Operated Video and stereo Baited Remote Underwater Video to take random replicated measures of finescale habitat and fish assemblages stratified by six distinct lagoon zones at each location. Statistical analysis revealed distinct fish assemblages and biophysical habitats within each of the lagoon zones sampled. Finescale biophysical habitat as represented by percent cover of habitat forming benthos described on average 47% of the variation in fish assemblages within the sanctuary zone habitats. When compared to variation in fish assemblages at fished locations target species including *Lethrinus atkinsoni*, *Lethrinus nebulosus*, *Epinephelus rivulatus, Lutjanus fulviflamma* and *Carangoides fulvoguttatus* were variously more abundant and larger. Non target species including invertivores such as *Thallasoma lunare* and herbivores such as *Acanthurus triostegus* were also more abundant while planktivores particularly *Chromis viridis* were found to be less abundant. Overall species richness and diversity was also higher at protected sites. The strength of this response varied between the six lagoon zones depending upon the species and their habitat affinities. The strength of this response was also moderated by seasonal and inter-annually variable processes affecting trophic groups and species differently. Fishing impacts had very different implications for overall fish assemblage structure depending on the spatial and temporal distribution and particular habits of target and non-target species.

Herbivorous fish of Ningaloo

Peter Michael

Hon. Student; Edith Cowan University, Joondalup, WA

Herbivory is an important ecological factor that can control primary productivity and producer structure in a wide range of natural ecosystems, both terrestrial and marine. Herbivory is particularly high in coral reef ecosystems, where herbivorous fishes play a major role in shaping the overall benthic community structure. This relationship between herbivorous fishes and algae represents one of the key natural processes responsible for the persistence of coral reefs against potential 'phase-shifts' by mediating the competition for space between corals and benthic macro-algae, essentially maintaining the system in an animal dominated state.

Current literature describes a number of functional groups which have been ascribed to herbivorous fish on coral reefs based on their shared ecological roles and functions. However, the mechanical removal of benthic algae in coral reef systems by these groups is only partially understood, and little published data exists quantifying the impact of particular species or functional groups (predominantly those from Family: Acanthuridae, Scaridae, Kyphosidae and Siganidae) in maintaining the standing algal biomass at low levels amongst coral reefs.

The core of my research is driven by the need understand the species-specific rates of fish herbivory along the Ningaloo Reef in order to correctly identify the key species which maintain natural ecosystem processes, and ultimately underpin effective coral reef management. Ningaloo Reef provides a unique opportunity to investigate algal-herbivore interactions without the potentially confounding affects of overfishing and poor water quality.

In this study, I will use a combination of descriptive and experimental approaches to quantitatively characterise species-specific algal-herbivore interactions. In particular, remote video techniques coupled with in-situ algal bioassays (*Sargassum myriocystum*) will be used to quantify spatial variation in macroalgal herbivory across reef habitats (lagoon, reef flat and outer reef) and along the different regions of the reef (Bundegi, Mangrove Bay, Mandu, Osprey, Pt. Cloates, Maud and Gnaraloo). This study will be the first of its kind to be applied over such a large spatial scale in order to characterise fish herbivory within an entire coral reef system.

Ecology of Indo-Pacific humpback dolphins (*S. chinensis*) and bottlenose dolphins (*Tursiops sp*.) in Ningaloo Marine Park

Kristel Wenziker

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Delphinids are high level predators that rely on a healthy and intact ecosystem. Two species of coastal dolphins are the focus of this study, Indo-Pacific humpback dolphins, *Sousa chinensis*, (henceforth humpback dolphins) and bottlenose dolphins (*Tursiops sp*.).

The Ningaloo reef region has in recent years experienced significant development due to the iconic nature of the area and anthropogenic impacts on cetaceans such as boating harassment, noise and commercial wildlife interaction tours are likely to continue to increase (CALM & MPRA, 2005).

In Shark Bay, in direct proportion to an increasing number of tour operators, there was a significant average decline in dolphin abundance over 13.5 years (Bejder et al., 2006). Other threats include decreases in prey abundance, ecosystem degradation and entanglement in fishing gear.

The IUCN status of humpback dolphins is data deficient (Jefferson et al., 2008) and the long-term performance target for cetaceans in Ningaloo Marine Park is "No loss of whale and dolphin diversity and abundance as a result of human activity in the reserves" (CALM & MPRA, 2005, p57). However, to-date no studies have been undertaken on delphinids, and there is an urgent need for initial assessment of these populations and their ecological needs.

Two study sites are proposed, Coral Bay and Tantabiddi lagoon. Boat-based surveys will be undertaken and standard photo-identification and mark-recapture methods will be used to obtain population estimates. Observations of dolphin distribution, behaviour and habitat usage will be combined with biodiversity and benthic habitat maps. This will clarify their habitat preferences and determine drivers of distribution, such as prey distribution and predator avoidance; predictive modelling of critical areas will be undertaken. Recommendations for their conservation and management, and a contribution to the assessment of the conservation status of the humpback dolphin at a national level will be made. This study should shed new light on the importance of the region to humpback dolphins and bottlenose dolphins.

Additional Student Abstracts

Reef Encounters: how repeat visitors to the Ningaloo region may be impacted by tourist management changes

Pippa Chandler

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This research will examine the experiences and attitudes of people who holiday regularly in the Ningaloo Reef area, a rapidly changing part of Australia's North West.

The area is popular with West Australian visitors who value the area's beauty and isolation, and often have strong attachments to specific campsites or caravan parks. Impending changes to the way land is managed at Ningaloo, notably changes from pastoralist to government control, may disrupt or restrict the ways in which these individuals experience the region.

Using semi-structured interviews with repeat visitors (RVs) to the region, this research explores how management changes to the area may effect these individuals' interactions with their physical and cultural surroundings.

It asks what motivates a visitor to return to any destination repeatedly, and whether RVs' interact with their environments differently from other types of visitors. It will analyse these people's travel experiences in relation to academic literatures on place and place-attachment, social impacts of tourism, rural change and repeat-visitation.

In doing so, it will evaluate the potential influence of RVs' attitudes and values on future tourism/planning in the region and elsewhere in coastal Australia.

Sustainable Camping along the Ningaloo Coast: Environmental Impact assessment, Resource Use and Camper Preferences

Anna Lewis

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While coastal areas are prime destinations for outdoor recreation activities, they are also dynamic and highly sensitive to impacts. Despite its isolated location, the Ningaloo coastline is emerging as a prominent camping location in Western Australia. Visitors have a choice to camp at either regulated or unregulated campsites, which differ in management structure, restrictions, cost and facilities. It has been argued by David Wood (2003) that the future of tourism in the Ningaloo Marine Park depends on its sustainability, largely through maintenance of the natural environment.

Given the current plan to develop multiple tourism ‘nodes’ along the Ningaloo coast, including a number of camping nodes, the focus of this study is to provide baseline data to aid in sustainable planning of both unregulated and regulated campsites within the Ningaloo Marine Park. This study will have three aspects: Initial environmental impact assessment of campsites; resource use (water/energy use, waste production) of campers; and user preferences of campers concerning facilities and restrictions.

Both qualitative and quantitative methods will be utilised. Initial impact assessments will assess individual campsites’ camp area, vegetation cover and type, litter and social trails. Resource use and preferences of campers will be determined through ‘choice model’ questionnaires and ‘semi-structured’ interviews. Unregulated camping areas to be assessed include Blowholes, Warroora Station, Cardabia Station, and the Federal Defence land. Regulated campsites include Quobba, Red Bluff, Three Mile Camp, and campsites within Cape Range National Park. Fieldwork is expected to be undertaken throughout 2009.

Initial impact assessments and identification of key environmental indicators will assist future monitoring. Resource use data will be analysed using the Ecological Footprint model to determine carrying capacity of campsites. A satellite map will provide a snapshot of the suitability of the sampled campsites as potential camping nodes, in consideration of probable increased visitation levels at Ningaloo. User preferences may then be used to further inform future planning and management. The data will contribute to a stronger understanding of campsite sustainability, with regard to campsite placement and facilities. This research will also address international information gaps within the field of recreation ecology in coastal areas.

The influence of place attachment on the management of marine parks and their hinterlands

Joanna Tonge

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Recently completed fieldwork by Murdoch University (Beckley, Smallwood and others) indicates that 55% of visitors to the Ningaloo Marine Park have been there before, and 82% intend to visit again. Interestingly, 44% of these visitors have always stayed at the same place, which is extraordinarily high site fidelity. Such fidelity suggests that place attachment is likely to be a strong influence on how visitors behave, what their expectations are and how they respond to policy and management changes. Extensive research in North America has described the different forms of place attachment expressed by visitors to national parks and forests and its effects on visitors' responses to management. Similar research has not been undertaken in Australia and additionally place attachment in marine environments has received little attention in Australia or elsewhere.

Planning, developing and managing protected areas requires an understanding of the attributes and values of these areas. However, how can managers consider place attachment when making management decisions? Understanding the connections between quality of life, sense of place, place attachment and satisfaction is likely to assist managers in providing protected areas where both biodiversity and the quality of visitors' experiences are assured.

This project will focus on measuring and gaining an understanding of visitors' attachment to the Ningaloo Marine Park as well as gaining an insight into the attachment of locals and managers. Such an understanding will better inform management and development decisions. Potential outcomes include: identifying methods for determining place attachment in marine environments; determining associated measures of place attachment; and providing information on how different forms of place attachment might contribute to different responses to proposed changes in management.

Coral associated microbes of Ningaloo Reef

Janja Ceh

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Over the past several decades, coral reefs worldwide have been subjected to unprecedented degradation. Recently the importance of microbial-coral interactions has been recognised with studies demonstrating a conserved microbiota associated with some species potentially active in maintaining coral health. However the specificity of these associations is still not well understood and little is known about the dynamics of coral-microbial associations over time and space.

This study investigates the dynamics of coral-associated microbial communities over a one year period, in the Ningaloo reef system of Western Australia. The study specifically looks at the seasonal changes in diversity and community structure of microbes harboured by corals and presents the findings of data acquired from the first nine months of study.

Samples were collected every three months, with additional sampling before and after coral spawning, to determine how microbial communities changed through this event. Three different coral species were examined and comparisons made between brooders versus spawners and massive versus branching corals. Mucus samples of corals were taken in situ and the diversity and community structure of the associated microbes were analysed by molecular techniques including phylogenetic analysis of 16S rRNA gene clone libraries.

The dynamics of coral-microbial associations over space and time is discussed. Considering the uniqueness of Ningaloo Reef in terms of its location on the western side of a continent and the associated unusual oceanographic regime, this data provides interesting and novel insights

Movement patterns of Serranids as they relate to marine park planning at Ningaloo Marine Park

Jason How

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Serranids (groupers) are often targeted by fishers resulting in significant fishing pressure on their populations. Due to their general sedentary nature, they often benefit from protection of marine protected areas.

This study is examining the movement patterns of twenty individual fish representing five species of Serranid with acoustic tags and an array of receivers. This project forms part of a larger CSIRO project, which is tracking numerous fish and shark species through the Mangrove Bay sanctuary zone and adjacent fished areas.

The project on serranids aims to examine the general movement patterns of these fish as well as identify any potential natural barriers to movement to possible spawning aggregation sites. Data collected on these highly exploited species will provide valuable information on their scales and patterns of movement that will benefit planning MPAs.

To date, the twenty tagged fish have been tracked over a six month period, and analysis is underway.

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 and trophodynamics.

Mark Langdon

PhD Student, Murdoch University, Murdoch, WA

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. However, the relative importance of the role of sea urchins in influencing the composition and structure of coral reef habitats has rarely been explored.

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, distribution, and trophic relationships at Ningaloo Marine Park. The indirect effects of different closure regimes (e.g. Marine Protected Areas 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.

Assessment of coastal groundwater and linkages with Ningaloo Reef

Deanna Wilson

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Little is known about the groundwater system and its connectivity with Ningaloo reef but there is sufficient information to indicate that groundwater discharge from the hinterland to the reef system is a significant process which probably has linkages to issues such as stygofauna habitat, water chemistry and biodiversity patterns within the reef lagoon. Groundwater influx is expected to be responsive to recharge and runoff events, tidal oscillations, seasonal variations and storm events. Groundwater discharge has been shown to be significant within the lagoon of the Great Barrier Reef, for example by delivering nutrients to the reef system, and analogies are to be expected with Ningaloo Reef due to the presence of a karst hinterland and distinctive palaeochannel systems encroaching into the reef lagoon.

Some of the project objectives will be utilisation of shared field time, including shared seabed bathymetric and swath data relevant to project objectives and also shared access to remote sensing data through projects within WAMSI Node 3 and the CSIRO Wealth from Oceans Flagship's Ningaloo Collaboration Cluster projects. The latter are particularly important with respect to remote sensing data sharing.

Project findings thus far have been that spatial patterns do exist in the groundwater data for the Ningaloo Reef Marine Park and it is possible to predict areas where groundwater discharge is likely using a combination of fresh groundwater indicators such as well locations, karst, Ficus and stream discharge. Predictive analysis has highlighted a number of 'likely areas' for groundwater discharge and will reduce the duration of groundtruth studies and area to be covered by these studies which are planned for 2009. A preliminary map of the groundwater system has also been composed based on the predictive analysis. Further, preliminary work has been undertaken on hyperspectral data analysis in the predicted areas to determine if a particular spectral signature exists for groundwater discharge in a marine setting and to further refine the study sites. A more detailed investigation will be undertaken in the second year of the project.

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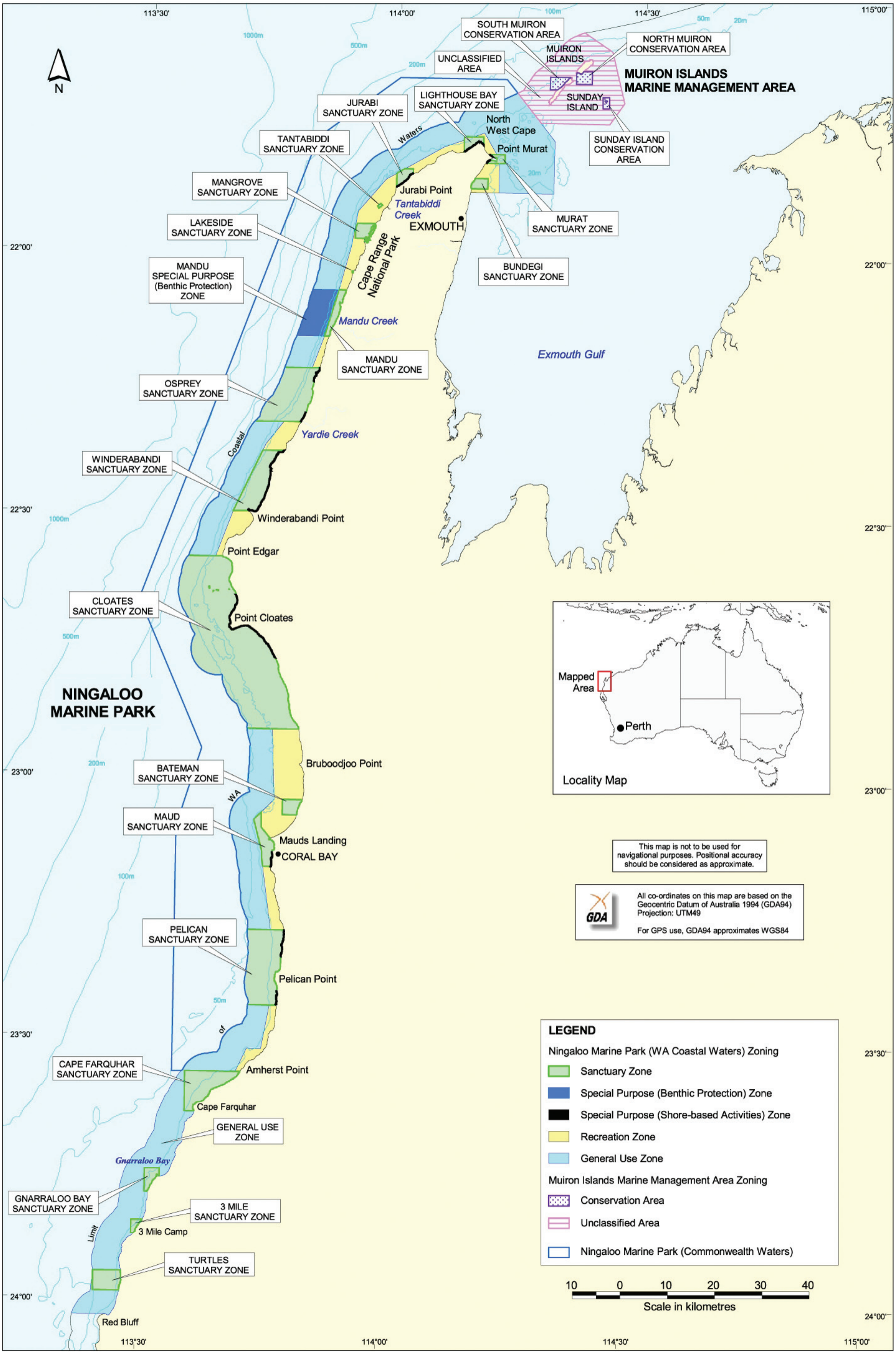
NINGALOO MARINE PARK
MUIRON ISLANDS MARINE MANAGEMENT AREA
SOUTH MUIRON CONSERVATION AREA
NORTH MUIRON CONSERVATION AREA
MUIRON ISLANDS
UNCLASSIFIED AREA
SUNDAY ISLAND
SUNDAY ISLAND CONSERVATION AREA
LIGHTHOUSE BAY SANCTUARY ZONE
JURABI SANCTUARY ZONE
TANTABIDDI SANCTUARY ZONE
MANGROVE SANCTUARY ZONE
LAKESIDE SANCTUARY ZONE
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WINDERABANDI SANCTUARY ZONE
CLOATES SANCTUARY ZONE
BATEMAN SANCTUARY ZONE
MAUD SANCTUARY ZONE
PELICAN SANCTUARY ZONE
CAPE FARQUHAR SANCTUARY ZONE
GENERAL USE ZONE
GNARRALOO BAY SANCTUARY ZONE
3 MILE SANCTUARY ZONE
TURTLES SANCTUARY ZONE
MURAT SANCTUARY ZONE
BUNDEGI SANCTUARY ZONE
North West Cape
Point Murat
Jurabi Point
Tantabiddi Creek
EXMOUTH
Cape Range National Park
Mandu Creek
Exmouth Gulf
Yardie Creek
Winderabandi Point
Point Edgar
Point Cloates
Bruboodjoo Point
Mauds Landing
CORAL BAY
Pelican Point
Amherst Point
Cape Farquhar
Gnarraloo Bay
3 Mile Camp
Red Bluff
Coastal Waters
WA
of
Limit
N
113°30'
114°00'
114°30'
115°00'
22°00'
22°30'
23°00'
23°30'
24°00'
1000m
500m
200m
100m
50m
20m
Mapped Area
Perth
Locality Map
This map is not to be used for navigational purposes. Positional accuracy should be considered as approximate.
GDA
All co-ordinates on this map are based on the Geocentric Datum of Australia 1994 (GDA94)
Projection: UTM49
For GPS use, GDA94 approximates WGS84
LEGEND
Ningaloo Marine Park (WA Coastal Waters) Zoning
Sanctuary Zone
Special Purpose (Benthic Protection) Zone
Special Purpose (Shore-based Activities) Zone
Recreation Zone
General Use Zone
Muiron Islands Marine Management Area Zoning
Conservation Area
Unclassified Area
Ningaloo Marine Park (Commonwealth Waters)
10 0 10 20 30 40
Scale in kilometres