The WAMSI Conference

WA Maritime Museum, Fremantle
September 19 & 20, 2011

www.wamsiconference.org.au

western australian
marine science institution

Western Australian Marine Science Institution
Hackett Drive Entrance 3
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WAMSI would like to thank WA Tourism, WA Museum, CSIRO and Peter Strain for the use of their images.

Welcome to the WAMSI Conference

The WA Marine Science Institution (WAMSI) was formed in early 2006 as a collaboration of state, federal, industry and academic entities that have come together in a way that supports cooperation and scientific rigour around the strategic marine science needs for the State of Western Australia. Independent, peer-reviewed public good research has been the hallmark under the banner: Bettter Science, Better Decisions. The WAMSI conference in September is a unique event that represents the culmination and celebration of five years worth of research effort and $87million dollars worth of research projects.

The WAMSI Conference will bring together some of Australia's most esteemed marine scientists and their teams who together will synthesise the remarkable outcomes and achievements of their collaboration.

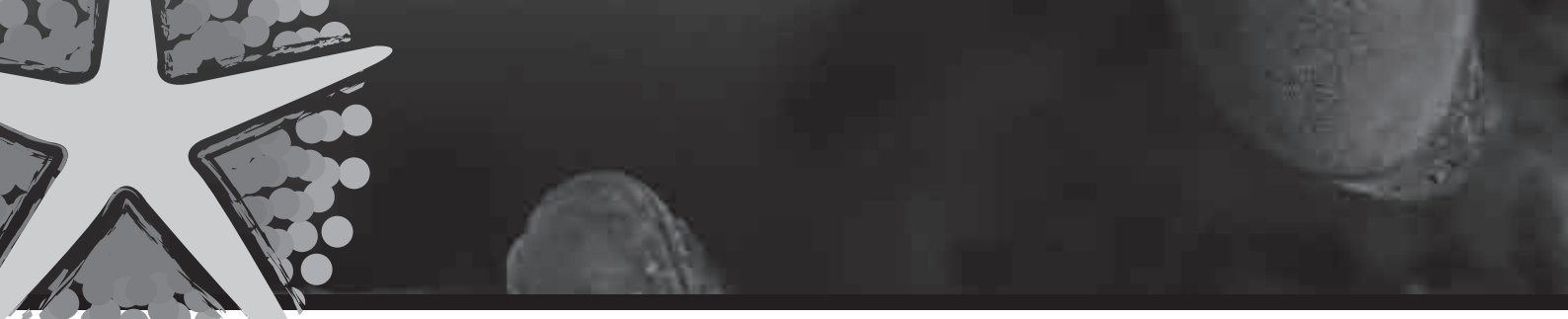
This conference will provide a great platform for scientists to show their research with users of the information, including managers, decision makers, consultants/ and the community. It will also be an invaluable opportunity for all stakeholders influenced by the WAMSI's three key integrating themes – ocean systems forecasting, biodiversity conversation and natural resource management – to participate.

The conference is being staged at the magnificent facilities of the Western Australian Maritime Museum, Fremantle – where we were officially launched as an institution in 2007.

A major marine underwater technology exhibition at the Museum coincides with the WAMSI Conference.

I welcome your participation and look forward to meeting you during WAMSI Conference.

Dr Peter Rogers
WAMSI Chair



Conference logistics

The WAMSI Conference will run as two discrete sessions over September 19 and 20.

Conference Room 1 will contain the following presentations:

- Node 1 – Strategic research on Western Australian marine ecosystems
- Node 3 – Conserving marine biodiversity 3

Conference Room 2 will contain the balance of presentations:

- Node 2 – Climate processes, predictability and impacts in a warming Indian Ocean
- Node 4 – Sustainable ecosystems for sustainable fisheries
- Node 5 – Biodiscovery, biotechnology and aquaculture
- Node 6 – Ocean predictions for the offshore and coastal engineering

We have chosen to operate in this manner for several reasons.
Firstly – we wanted to ensure we offered as many project leaders as possible the opportunity to present their work. To provide that as entirely plenary conference would have meant we met for four days! And so, we chose to divide the event into two streams and enable delegates to move between rooms as much as practicable.

But also, we wanted to ensure the End of WAMSI 1 conference was able to take place at what is considered "the spiritual home of WAMSI" – the Maritime Museum. The room capacities here at the Museum provide some limits to the numbers we can seat in a plenary session.

And so, the end result is two discrete concurrent themes. We have asked delegates to nominate which rooms/ sessions they wish to attend. Depending on our final numbers there may be some flexibility to that approach.

We hope all conference delegates will stay on at the completion of each day for a celebration sundowner in the Exhibition Foyer.

We trust that you will enjoy your WAMSI Conference.

For any assistance or inquiries in relation to this conference, please contact our conference managers, Esther Price Promotions on +61 8 9525 9222.

For assistance on-site over the two day event please contact

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0412 77 88 79
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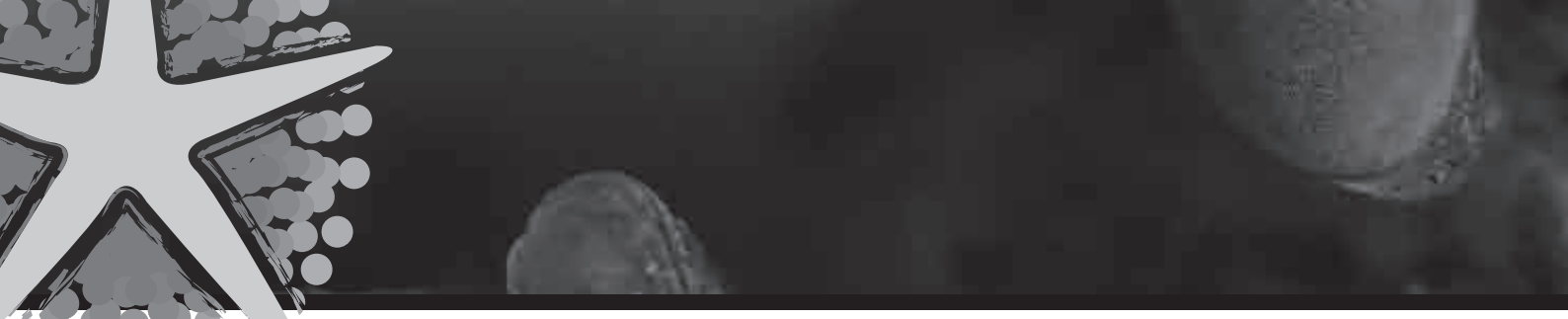
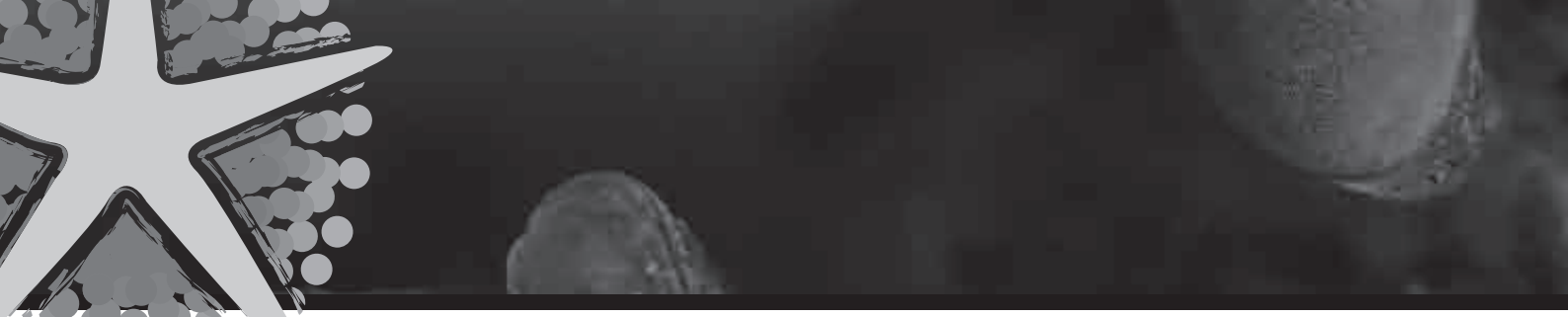


Conference Program

Day 1 Monday 19 September 2011

Registration - from 8.00am			
Concurrent session 1		**Concurrent session 2**	
9.00am	Welcome by the WA Museum, followed by Welcome to Country	9.00am	Welcome by the WA Museum, followed by Welcome to Country
9.05am	Celebrating WAMSI 1's science accomplishments *Simon Woodley*	9.05am	The big picture: An overview of the WAMSI contribution to building the capacity of marine science *Peter Rogers, WAMSI Chairman*
9.25am	The big picture: An overview of the WAMSI contribution to building the capacity of marine science *Peter Rogers, WAMSI Chairman*	9.25am	Celebrating WAMSI 1's science accomplishments *Simon Woodley*
Node 3: Conserving Marine Biodiversity		**Node 4: Sustainable ecosystems for sustainable fisheries**	
9.45am	Node 3 Leader's overview *Chris Simpson, Department of Environment and Conservation*	9.45am	Node 4 Leader's overview *Rick Fletcher, Department of Fisheries - Implementing ecosystem-based fisheries' management*
9.55am	WFO Cluster - An overview of the Ningaloo Collaboration Cluster *Neil Loneragan, Murdoch University*		
10.10am	Node 3 Knowledge transfer *Kelly Waples, DEC*		
10.20am -10.50am	Morning tea IMMERSE Exhibition Hall	10.20am - 10.50am	Morning tea upper level balcony
10.50am	Node 3 Near reef oceanic processes and nutrient dynamics *Anya Waite, UWA*	10.50am	Node 4 Applying the EBFM framework Overview *Presentation led by Dan Gaughan, Department of Fisheries*
11.05am	Node 3 Deepwater habitats and biodiversity *Andrew Heyward, AIMS*	11.20am	Node 4 Trophic interactions and ecosystem modelling *Neil Loneragan, Murdoch University, with Matt Pember, Murdoch University*
11.25am	WFO Cluster Habitats and Biodiversity of Ningaloo Reef lagoon and coastal areas *Halina Kobryn, Murdoch*	11.50am	Node 4 Captured species assessments overview *Brett Molony, Department of Fisheries*
11.40am	Node 3 Effectiveness of sanctuary zones – overview *Russ Babcock, CSIRO*		
12.00pm	Node 3 Fish biodiversity and assemblages *Euan Harvey, UWA*	12.20pm	Node 4 Question session
12.15pm	AIMS The Ningaloo Atlas *Tyrone Ridgway, AIMS*		
12.30– 1.30pm Lunch IMMERSE Exhibition Hall			

Node 3 Continued: Conserving Marine Biodiversity		Node 4 Continued: Sustainable ecosystems for sustainable fisheries	
1.30pm	Node 3 Growth history, geomorphology and sediments of the Ningaloo Reef and adjacent shelf *EmilyTwiggs, Curtin University*	1.30pm	Node 4 Socio-economic implications of EBFM Overview *Led by Malcolm Tull, Murdoch University* Node 4 Modelling recreational fishing behaviour *Paul McLeod, UWA*
1.45pm	Node 3 Oceanographic processes and water circulation *Chari Pattiaratchi, UWA*	1.55pm	Socio-Economic Assessment of Scalefish Fisheries (Inshore Demersal) in the West Coast Bioregion *Seamus McElroy, Murdoch University and Joseph Christensen, UWA*
2.00pm	Node 3 Coastal groundwater and the linkages to Ningaloo Reef *Alexandra Stevens, Curtin*	2.15pm	Node 4 Assessment of marine communities overview *Euan Harvey, UWA*
2.15pm	Node 3 Tagging and tracking the world's largest fish *Mark Meekan, AIMS*	2.25pm	Node 4 Assessments of the status of community structure based on fishery independent data *Peter Coulson, Murdoch University*
2.30pm	Node 3 Trophic cascade effects and herbivory *Glen Hyndes, Edith Cowan University*	2.35pm	Node 4 Development and validation of an estuarine health index using fish community characteristics *Chris Hallett, Murdoch University*
2.45pm	Node 3 Monitoring the health of benthic communities *Martial Depczynski, AIMS*	2.45pm	Node 4 Assessment of marine communities and the impact of anthropogenic influences *Dan Smale and Tim Langlois, UWA*
3.00pm	Node 3 Intertidal Invertebrates *Dr Anne Brearley, UWA*	3.00pm	Node 4 questions
3.15pm - 3.50pm	Afternoon tea IMMERSE Exhibition Hall	3.15pm - 3.50pm	Afternoon tea upper level balcony
Node 3 continued : Conserving Marine Biodiversity		**Node 2: Climate processes, predictability and impacts in a warming Indian Ocean**	
3.50pm	WFO cluster visitor destination model *Tod Jones, Curtin University*	3.50pm	Node 2 Leader's overview *Ming Feng, CSIRO* - Climate variations across time scales – seasonal, interannual, decadal and long term trends
4.10pm	WFO cluster patterns of human use *Lynnath Beckley, Murdoch University*	4.05pm	Node 2 Understanding and predicting impacts of the Indian ocean dipole *Harry Hendon and Bureau of Meteorology*
4.25pm	Node 3 ELFSim *Richard Little, CSIRO*	4.25pm	Node 2 Impact of assimilating salinity on the simulated mean state and variability in a coupled seasonal forecast model *Maggie Zhao, Bureau of Meteorology*
4.40pm	WFO Cluster Management strategy evaluation *Fabio Boschetti, CSIRO*	4.40pm	Node 2 Seasonal and intra-seasonal variability along Australia's NW and Northern Shelves *Andreas Schiller, CSIRO*
4.55pm	Closing remarks	4.55pm	Closing remarks
5.00pm - 6.30pm	**Sundowner** **WAMSI Chairman's address - A celebration of WAMSI 1** **IMMERSE Exhibition Hall**		



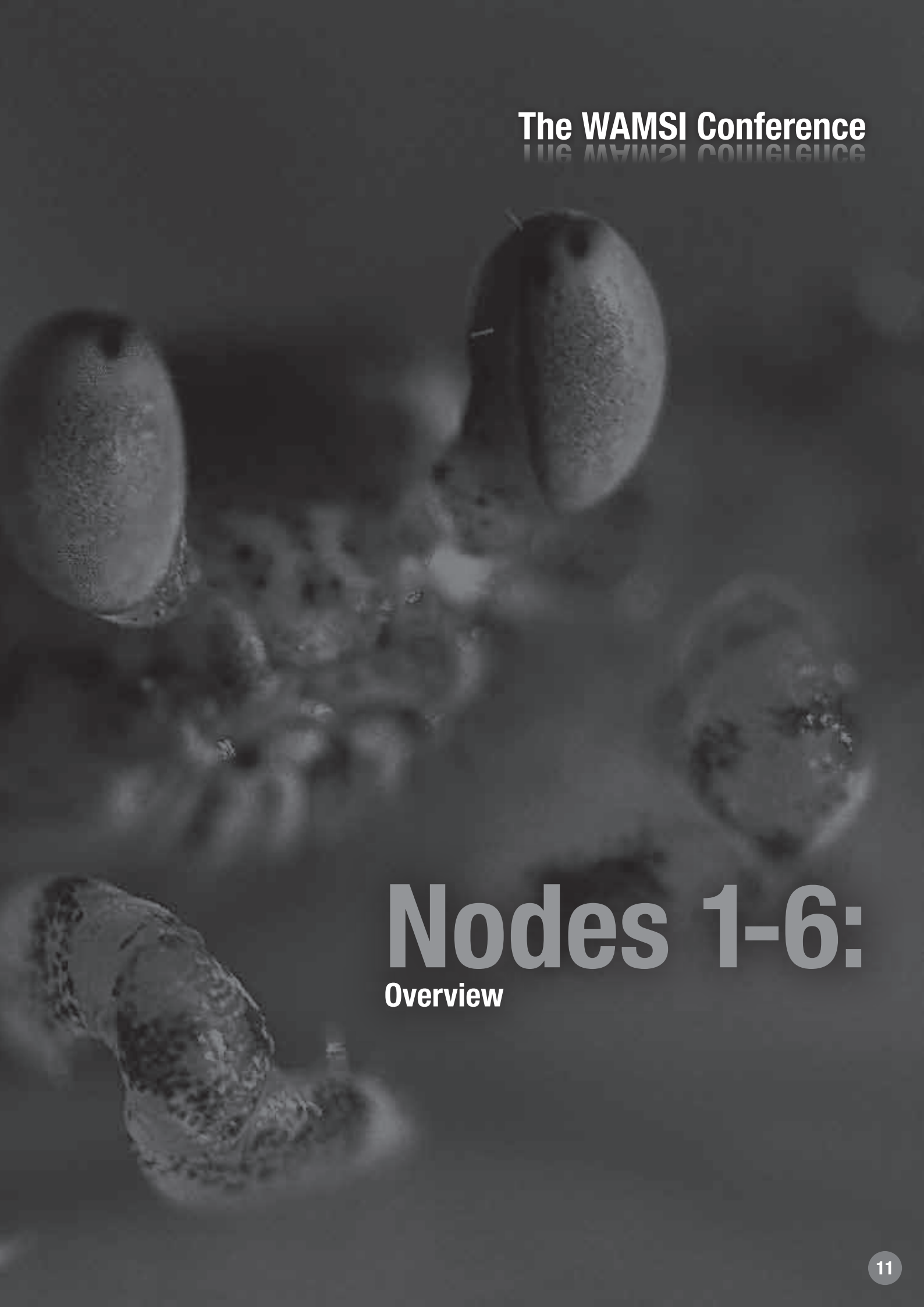
Conference Program

Day 2 Tuesday 20 September 2011

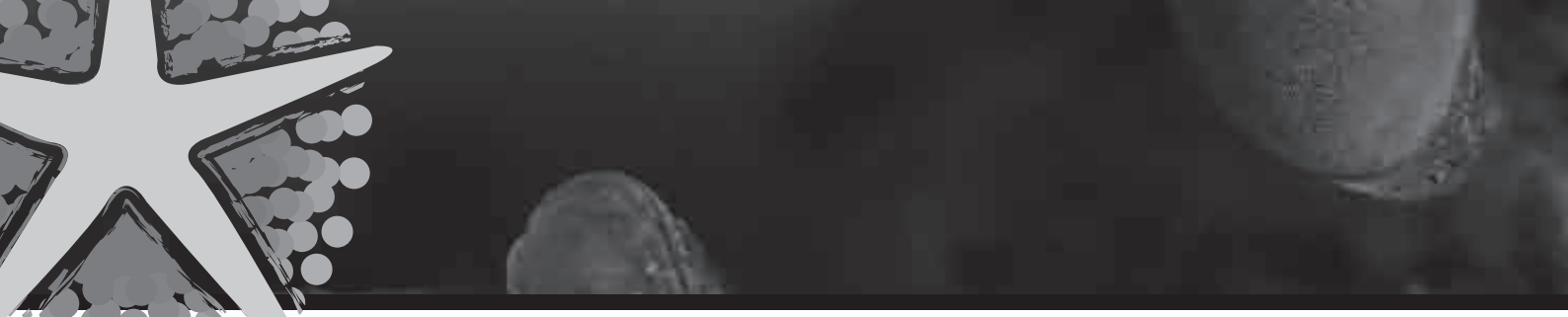
8.00am – Registration desk open

Concurrent session 1		Concurrent session 2	
9.00am	Welcome back and housekeeping	9.00am	Welcome back and housekeeping
Node 1: Strategic research on Western Australian marine ecosystems		**Node 2 Continued: Climate processes, predictability and impacts in a warming Indian Ocean**	
9.05am	Node 1 Leader's overview *John Keesing, CSIRO*	9.05am	Node 2 Strengthening of the East Australian Current and weakening of the Leeuwin Current in a warming climate: results from dynamical downscaling *Chaojiao Sun, CSIRO*
9.25am	Node 1 Oceanography overview *Peter Craig, CSIRO*	9.25am	Node 2 Downscaling future ocean scenarios to Ningaloo Reef *Richard Brinkman, AIMS*
9.45am	Node 1 South West WA Continental Shelf hydrodynamics *Liejun Zhong, CSIRO*	9.45am	Node 2 and 4 Warming trends of ocean temperatures off the Western Australian coast and implications for fisheries *Nick Caputi*
10.05am	Node 1 South West WA Continental Shelf biogeochemistry *Jim Greenwood, CSIRO*	10.05am	Node 2 Meso-scale variability of the Leeuwin Current influences the distributions of larval fishes off Western Australia *David Holliday, Murdoch University*
10.25am	Node 1 Southwest Australian Coastal Biogeochemistry *Graham Symonds, CSIRO*	10.25am	WAMSI CEO Report *Steve Blake, WAMSI*
10.45am to 11.15am	Morning tea IMMERSE Exhibition Hall	10.45am to 11.15am	Morning tea Upper Level Balcony
Node 1 Continued: Strategic research on Western Australian marine ecosystems		**Node 5: Biodiscovery, biotechnology and aquaculture**	
11.15am	Node 1 Marmion Lagoon Biogeochemistry *Jim Greenwood, CSIRO*	11.15am	Node 5 Leader's overview *Howard Shawcross, Department of Commerce - Marine biodiscovery, biotechnology and aquaculture: the blue farm*
11.35am	Node 1 Water retention and alongshore connectivity off the WA coast *Ming Feng, CSIRO*	11.35am	Node 5 Marine biodiscovery and biotechnology – WA Marine Bioresources Library *Jane Fromont, WA Museum*
11.55am	Node 1 Sediment biogeochemistry across a sediment nutrient gradient *Martin Lourey, CSIRO*	11.55am	Node 5 Biomolecular diversity and partnered biodiscovery *Peter Leedman, UWA*
12.15pm	Node 1 Assessing the role of filter feeders in Marmion Lagoon *Joanna Strzelecki, CSIRO*	12.15pm	Node 5 Quorum sensing *Jamie Summerfield, UWA*
12.35pm to 1.30pm	Lunch IMMERSE Exhibition Hall		

Node 1 Continued: Strategic research on Western Australian marine ecosystems		Node 6: Ocean predictions for the offshore and coastal engineering	
1.30pm	Node 1 Kelp patch dynamics *Russ Babcock, CSIRO*	1.30pm	Node 6 Leader's overview *Greg Ivey, University of Western Australia - Ocean science for offshore and coastal engineering*
1.50pm	Node 1 Larval fish assemblages and particle back-tracking providing insight into Eastern Indian Ocean boundary current processes *Lynnath Beckley, Murdoch University*	1.50pm	Node 6 Storm surge climatology and sea level variability for WA *Ivan Haigh, UWA*
2.10pm	Node 1 Data Interrogation and Visualisation Environment (DIVE) *Gary Carroll, CSIRO*	2.00pm	Node 6 Evolution of an extreme wave event from the ocean to the beach *Cyprien Bosserelle, UWA*
2.30pm	WAMSI CEO Report *Steve Blake, WAMSI*	2.15pm	Node 6 Perched beach morphodynamics: Sea breezes, storms and seasons *Shari Gallop, UWA*
2.50pm	WAMSI Data Management *Luke Edwards, WAMSI*	2.30pm	Node 6 Internal wave dynamics and climatology at Ningaloo Reef *Nicole Jones, UWA*
		2.45pm	Node 6 Turbulent mixing in bottom boundary layers forced by internal waves *Cynthia Bluteau, UWA*
		3.00pm	Node 6 Dynamics of the Browse Basin and Scott Reef *Matt Rayson, UWA*
3.15pm	Afternoon tea IMMERSE Exhibition Hall	3.15pm	Afternoon tea upper level balcony
3.50pm	Great moments of a PhD: A celebration of some of the lighter moments together with the achievements of PhD Students supported on scholarship by the WAMSI Education Program *Led by Chris Hallett, Murdoch University*	3.50pm	Node 6 Ocean glider deployments in WA – an overview *Chari Pattiaratchi, UWA*
4.10pm	Growing WAMSI into the Kimberley-Browse marine region *Steve Blake, WAMSI*	4.10pm	WAMSI Data Management *Luke Edwards, WAMSI*
4.30pm	Closing remarks and adjourn to the exhibition hall	4.30pm	Closing remarks and adjourn to the exhibition hall
4.50pm to 6.30pm	**Sundowner** **WAMSI Chairman's closing address "Looking forward to WAMSI 2"** **IMMERSE Exhibition Hall**		



Nodes 1-6:
Overview



Nodes: 1-6
Title: Celebrating WAMSI 1's Science Accomplishments

Author: Simon Woodley
Collaborators: Steve Blake, Peter Rogers
Institution: S & J Woodley Pty Ltd
Email: simon@magwood.com.au

Abstract

In mid 2006 the Western Australian State Government committed $21m over 5 years to the establishment of the Western Australian Marine Science Institution (WAMSI). Stakeholders and governments at all levels were concerned about increasing pressures from rapid coastal growth and development, catchment degradation, potential effects of burgeoning marine industries and about the effects of climate change and extreme events on important fisheries and coastal development. The potential threats to the unique and valued marine environment of WA and its resources prompted the idea of an integrated, multi-disciplinary research institution to address strategic information needs. Better information systems and predictive/planning tools were needed in order to manage responsibly coastal and marine use and development for economic and social benefit, while maintaining high quality public good environmental assets, such as Ningaloo Marine Park.

WAMSI has successfully undertaken a major program of strategic, multi-disciplinary, collaborative research over the past five years targeting large-scale issues of concern to government, industry and the general public. Significant additional resources have been added to the program from both the public and private sectors, including a new program on Dredging Science added in 2011. The result has been excellent science, new knowledge, better tools, improved collaboration and cooperation between research institutions and improved marine science capability. Baseline research has been undertaken in key areas such as the offshore Perth metropolitan region, Ningaloo Marine Park and parts of the Midwest coast to better understand variability in such phenomena as the Indian Ocean Dipole and ENSO events. Information and data have been shared and communicated to decision makers in government and industry for greater understanding of the marine systems and greater efficiency. Community engagement and stakeholder communication has been a significant component of the effort.

WAMSI 1 research results i.e. improved knowledge, better diagnostic and decision-making tools and enhanced capability, have already been of benefit to government and industry but will also be important in years to come for decision making on the use and conservation of WA's unique marine resources.

Nodes: 1-6
Title: WAMSI CEO Report

Author: Dr Steve Blake
Collaborators: Ms Linda McGowan
Institution: WAMSI
Email: steve.blake@wamsi.org.au

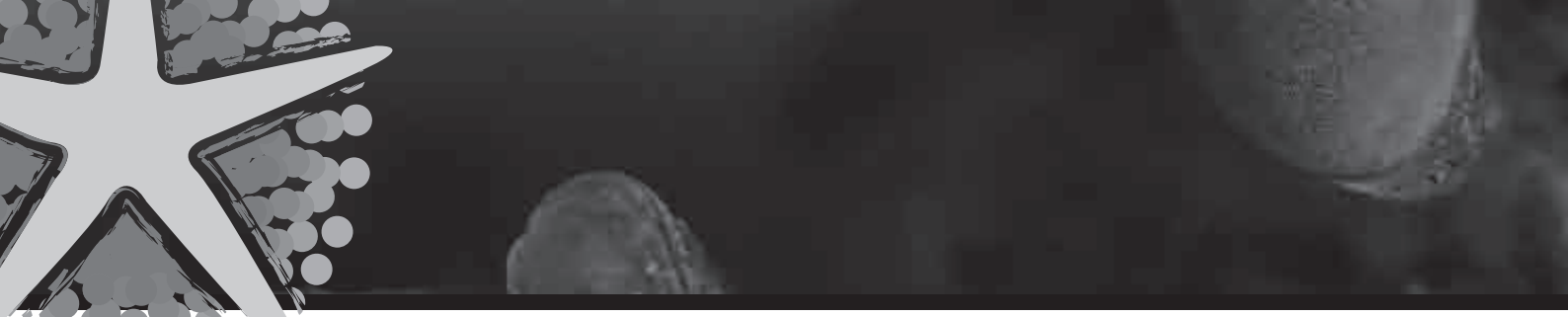
WAMSI commenced operations in July 2006 after an initial 12 month planning phase following the announcement of the WA State Government *Major Research Facility* establishment grant in July 2005. Four mutually supporting legal agreements were established at the outset of the WAMSI Joint Venture: *State Funding Agreement, Joint Venture Agreement, Centre Agent Agreement* and *the Model Project Agreement* and these have served the joint venture partners well. UWA was selected to be the Centre Agent [Legal entity] for the joint venture and has housed the WAMSI HQ and staff since commencement.

16 parties joined WAMSI at the outset, with members ranging from both State and Federal Governments, academia and industry. Membership of WAMSI and the Governing Board have remained very consistent throughout, with only one partner retiring and with two new members joining over the entire 5.5 year period.

The joint venture was officially signed off by the WA Premier in March 2007 and the Institution was subsequently launched by the WA Premier in May 2007. Subsequently, 87 projects have been undertaken under the WAMSI 1 umbrella involving 250 scientists from the 16 partner organisations. In this regard, the original $21 million grant from the State Government was leveraged to a total $96 million/5 yr entity. This involved $9 million of external projects beyond the scope of the six establishment Nodes.

Whilst the six Nodes of research have formed the backbone of the WAMSI 1 scientific endeavours and are the clear focus of this Conference, other elements have been undertaken in support of the Program and its partners including: marine data and information management [WAMSI is now part of the leadership group of the WA Node of the *Australian Ocean Data Network*]; science communications [over 35 public symposia and conferences have been delivered]; establishment of a Kimberley marine science activity [following on from the release of the coupled science/business case – *A Turning of the Tide - science for decision making in the Kimberley Browse Marine Region*, which has resulting in the funding of a Kimberley Node in WAMSI 2, commencing in January 2012]; support for the WA Node of IMOS [WA IMOS was funded by the State Government in May 2012 based on the business case presented]; the establishment of a strategic Dredging Science Node based on industry offsets funding; as well as ongoing executive support provided to the WAMSI Board, its four sub-committees and two operational groups to ensure full probity and management oversight of the expenditure of public monies.

WAMSI 1 will finish on time and on budget and the transition to WAMSI 2 has already commenced to ensure there is no hiatus between the two. The *catch-cry* for WAMSI has been: Better Science, Better Decisions and this has been based around a targeted approach focusing on: strategic research; science to support management and policy; independent QA/QC around science and project delivery; transparency around decision making and milestone reviews; and an independent mid-term Program Review that supported best practice around the joint venture's governance. The announcement of WAMSI 2 and the fact that so many new opportunities are being brought to WAMSI early by industry and via the partners, ensures the future is looking bright.



Nodes: 1-6
Project: WAMSI Data management

Author: Luke Edwards
Collaborators: IMOS / WAMSI / iVEC / WASTAC
Institution: Curtin University
Email: luke@ivec.org

Abstract
A large amount of marine data has been collected by WAMSI projects. In the past, marine data has often not been catalogued, described or stored in an appropriate repository. This makes discovery and re-use difficult as it requires personal knowledge of the work and/or researcher. To address this WAMSI has sought to create a legacy of marine data management by making all WAMSI data discoverable and accessible through the WA Node of the Australian Ocean Data Network (AODN).

Although there are costs involved with managing marine data correctly, there are many benefits in making marine data more discoverable and accessible. Reasons can include:

- Results can be verified (i.e. increases transparency) and protects researchers from unsubstantiated claims;
- Marine research is becoming more multi-disciplinary and so can benefit from drawing data from different fields/ researchers;
- Most marine data cannot be duplicated as it is a snapshot in time or is difficult / expensive to collect again;
- Old data can contribute to new research, enabling new discoveries and enabling time series to be created;
- Duplication of effort can be avoided, hence saving money.
- Meeting increasing requirements from funding agencies for the underlying research data (raw and processed) to accompany articles submitted for publication or provided to appropriate repositories;
- Additional publications and greater citation rate; and
- Wider recognition among peers and increased collaboration opportunities.

Within WAMSI project agreements there is a requirement for metadata to be created. Metadata is a description about the data and this is made public through an online catalogue - the WA-AODN Metadata Entry and Search Tool (MEST). This is harvested by the central Australian Ocean Data Network MEST and then by the Australian National Data Service (ANDS) Research Data Australia (http://services.ands.org.au/home/orca/rda/). ANDS optimises this information for search engine crawlers from companies such as Google. Hence it allows users to perform a 'Google search' to find marine data; they don't need to be aware of specific marine data catalogues. All WAMSI data will be made public through WAMSI partner data centres or from iVEC via the WA Node of AODN after an embargo period for researchers to publish. Metadata will also provide links to the data.

The overall aim of this WA 'regional node' of the AODN is to establish a sustainable marine data network in Western Australia which acts as the facilitator for the storage, management, discovery and exposure of marine data in Western Australia. All sectors of the WA marine community (Government, Universities, private industry and community groups) will be engaged to achieve this aim. For further information on the AODN refer to www.aodn.org.au.

Node: Establishment of a Kimberley Marine Science Node in WAMSI 2
Title: The WAMSI move into the Kimberley Browse Marine Region

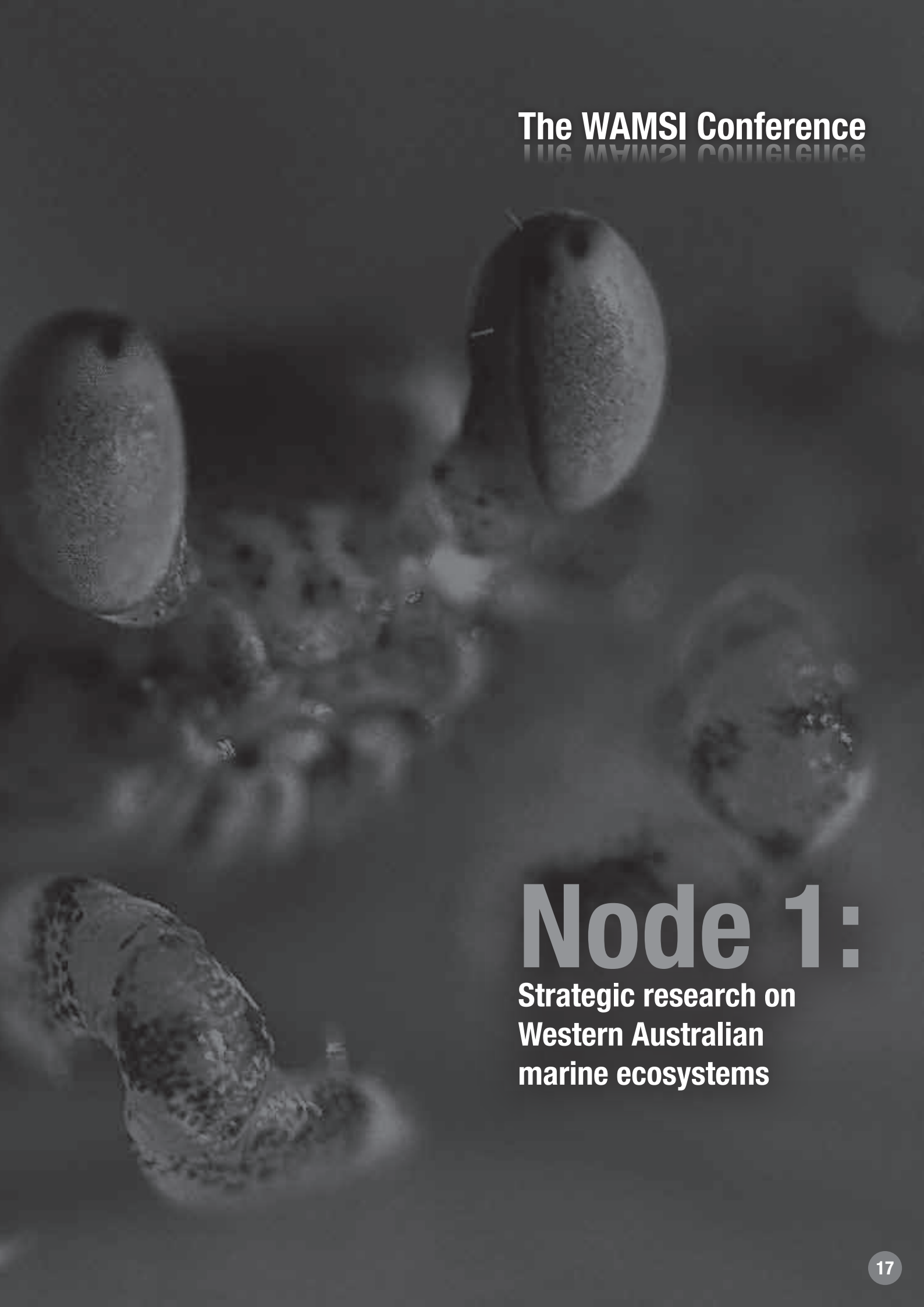
Author: Dr Steve Blake
Institution: WAMSI
Email: steve.blake@wamsi.org.au

WAMSI 1 involved 87 projects involving 250 scientists from the 16 partner organisations via six Nodes of research over a five year period. The majority of this work however, has taken place in the Rockingham – Exmouth Gulf geographic region. Large marine and coastal areas of the State remain relatively under-studied. In August 2007, the Board and Governors of WAMSI decided that WAMSI's future should be tied to providing key information for the relatively unknown Kimberley Browse marine region in order to service a range of stakeholder needs. The ultimate goal was the establishment of a large strategic Kimberley regional marine science activity. To further this ambition, it was decided to develop a coupled science/business case – *A Turning of the Tide - science for decision making in the Kimberley Browse Marine Region [Wood & Mills]*, which was released in November 2008 after an extensive 10 month writing and consultation period. The document was extensively researched and was well received by all sectors.

The WAMSI Board, with support from the Chairman and CEO, concurrently set about marketing the need for the establishment of a truly independent marine science activity in the Kimberley Browse region and undertaking some limited research to understand further the logistics involved in working in such an isolated region, very distant from Perth where the majority of WA's marine research expertise resides. This unrelenting effort over several years ultimately concluded in May 2011 with the State Government budget announcement of funding [$12 million over 6 years] to support a major new Node of research under WAMSI 2 commencing in January 2012. This WAMSI-led work will directly support the State's *Kimberley Science & Conservation Strategy* and broader needs, the latter pending the level of co-investment attained. The funding from the State Government will now be leveraged to maximise the investment in the new Node of research for the Kimberley Browse marine region.

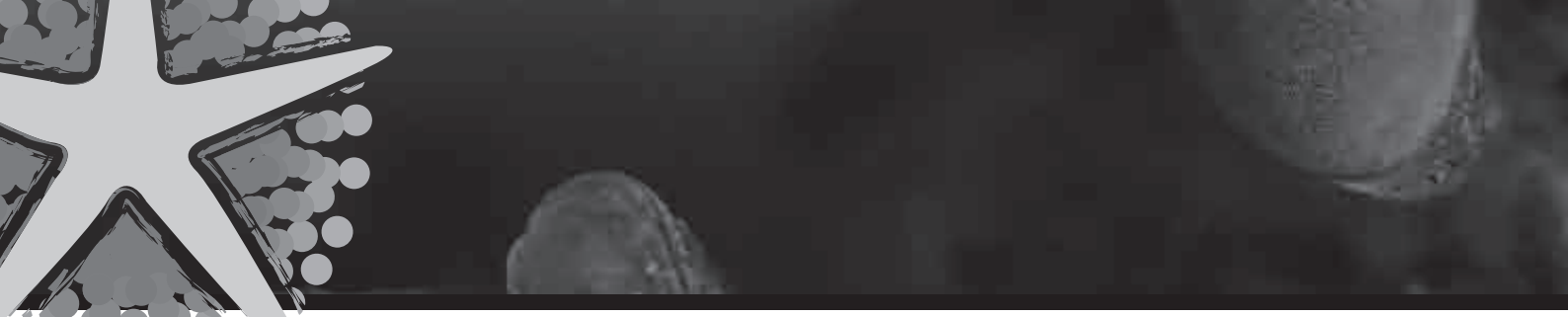
A WAMSI Marine Science Strategy document for the Kimberley Browse marine region has recently been approved by the WAMSI Board and formal science planning and related consultations are now underway and are due for conclusion by November 2011. This will be followed by a more detailed project planning phase with a view that projects can commence by May 2012. The science undertaken will support the establishment and ongoing monitoring of four new marine parks including: Camden Sound, Eighty Mile Beach, Roebuck Bay and the North Kimberley, as well as broader multiple-use and regional contextual issues.

This is a region that is under increasing scrutiny, both nationally and internationally, as some of the largest natural gas reserves in the world are found off the Kimberley coast in the Browse Basin and yet the area has very little information currently available in the public domain. All sectors will ultimately benefit from having access to truly independent marine science knowledge for a region that has been described as being within the last four per cent of intact tropical marine ecosystems remaining in the world.



Node 1:

Strategic research on Western Australian marine ecosystems



Node: 1
Title: Node 1 Leader's Overview

Author: John Keesing
Collaborators: Curtin, Edith Cowan, Murdoch, UWA, WA Museum, WA Chemistry Centre, DEC, WA Fisheries, IMOS, AIMS, Geosciences Australia
Institution: CSIRO
Email: John.keesing@csiro.au

WAMSI Node 1 was established with a vision to undertake strategic research on Western Australian coastal marine environments which could contribute to the knowledge base necessary to underpin sustainable management of Western Australia's marine environment. Specifically the Node 1 projects aimed to (a) characterise marine ecosystem structure and function, and (b) enhance our shared capacity to understand, predict and assess ecosystem response to anthropogenic and natural pressures. The initial Node 1 focus has been in south/mid-west of Western Australia but included a very large single habitat characterisation study of subtidal habitats of the Damper Peninsula in the state's north-west. That work has been the subject of other recent presentations so will not be covered in this Symposium.

The focus for research in Node 1 was guided by four high level science questions:

1. What are the large scale influences on the south-western Australian coastal environment?
2. How can we account for the highly productive characteristics of south-western Australian coastal ecosystems in an oligotrophic environment?
3. How do the south-western Australian coastal marine ecosystems respond to potential anthropogenic forcing?
4. What physical and ecological interactions are important determinants of south-western Australian coastal marine benthic habitats?

From these followed a set of objectives or deliverables for the Node. These deliverables are as follows:

- Hydrodynamic models downscaled sufficiently to explain and predict patterns of the cross-shore and longshore exchange of water, nutrients and particles between the lagoon and outer shelf regions.
- Quantitative nutrient budgets for coastal waters at both the shelf and lagoon scale
- Improved conceptual and coupled hydrodynamic-biogeochemical models for coastal waters incorporating seasonal and interannual variability and improved representation of benthic primary production and bentho-pelagic coupling at shelf and lagoon scales
- Models for assessing and predicting impacts of physical dynamics and nutrient enrichment on benthic habitats
- An assessment of the importance of physical forcing and ecological interactions among key functional in determining patterns of spatial mosaics in benthic habitats
- An assessment of key indicators of ecosystem condition with particular relevance to contrasting fished and non-fished areas
- An assessment of likely dispersal patterns for marine organisms based on coupled hydrodynamic and population genetic models
- Electronic delivery of data and models to management agencies, building on the development of the Data Interrogation and Visualisation Environment (DIVE) in SRFME.

The study has completed and delivered on each of the above objectives. The results have been presented to WAMSI in four volumes totalling over 700 pages and have contributed to a further 500 pages in published journal papers. Seven PhD students have contributed to Node 1, some having already completed their PhDs. Collectively the work has greatly increased our knowledge and understanding of the South-west Australian marine ecosystem in ways which can inform natural resource management well into the future.

Node: 1
Title: Node 1 Oceanography Overview

Author: Peter Craig
Collaborators: M.Feng, D. Slawinski, L.Zhong, J.Greenwood, G.Symonds
Institution: CSIRO
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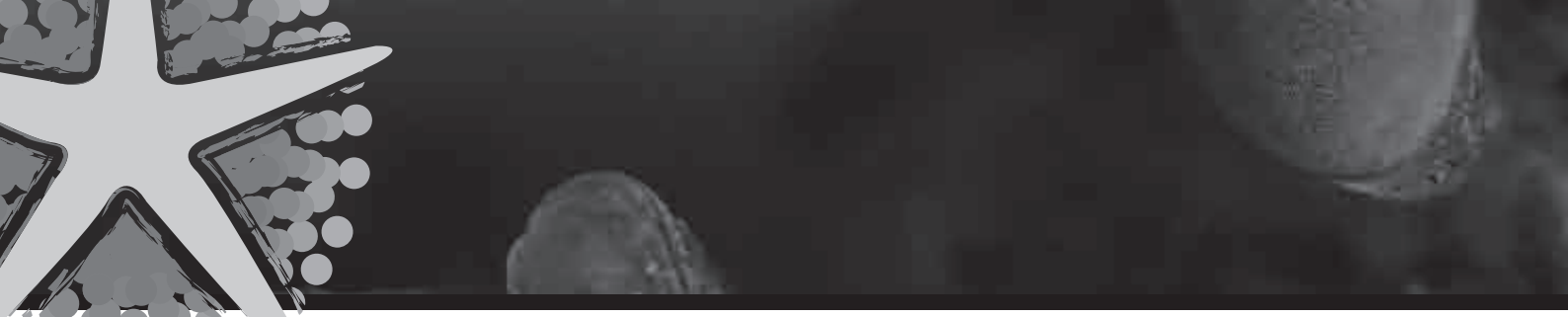
Abstract

In Node 1, we have considered the physical and biological oceanography at scales ranging from eastern Indian Ocean down to reefs and lagoons. At the broadest scale, we have been primarily focused on the role of the Leeuwin Current and its eddies in transporting biota, particularly larvae, along and across shore. At the shelf scale, the emphasis has been on the role of physical processes in the nutrient cycle and productivity. At this scale, waves, as well as currents, become important.

At reef and lagoon scale, waves can be the dominant driving mechanism for the circulation, and localised sources of nutrients appear to be important. Across these scales, different modelling approaches are appropriate, and different forms of data support the system analysis.



Node: 1
Title: South West WA Continental Shelf hydrodynamics

Author: Liejun Zhong
Collaborators: Ming Feng
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Abstract

The Leeuwin Current System is simulated in the fine-resolution Regional Ocean Modelling System (ROMS). Downscaled from a regional model, the ROMS model is driven by the same air-sea flux forcing as the Bluelink model and uses BRAN model outputs as open boundary conditions. The general features of the Leeuwin Current System and its seasonal variability simulated in the shelf-scale ROMS model agree reasonably well with the mother model BRAN and observations. The Leeuwin Current captured in the ROMS model reaches to 0.5 m/s in austral winter and becomes stronger as it moves toward the south. The Leeuwin Current is much weaker in austral summer; however, the northward Capes Current is developed inshore due to the prevailing southerly wind and cold water is brought up to the surface by the coastal upwelling. There is a distinct seasonal cycle in the transport of Leeuwin Current and monthly mean transport reaches up to 4.6 Sv in austral winter. However, the fine-resolution ROMS model indeed captures different circulations from the coarse-resolution BRAN model. For example, the shelf-scale model produces a much stronger northward Capes Current compared with BRAN. Both models have distinct seasonal cycle of Eddy Kinetic Energy (EKE), that is, higher EKE in austral winter and lower EKE in austral summer; however, EKE is higher in ROMS than in BRAN, which seems reasonable since flows tend to be more intense in ROMS with higher resolution.

Node: 1
Title: South West WA Continental Shelf biogeochemistry

Author: Jim Greenwood
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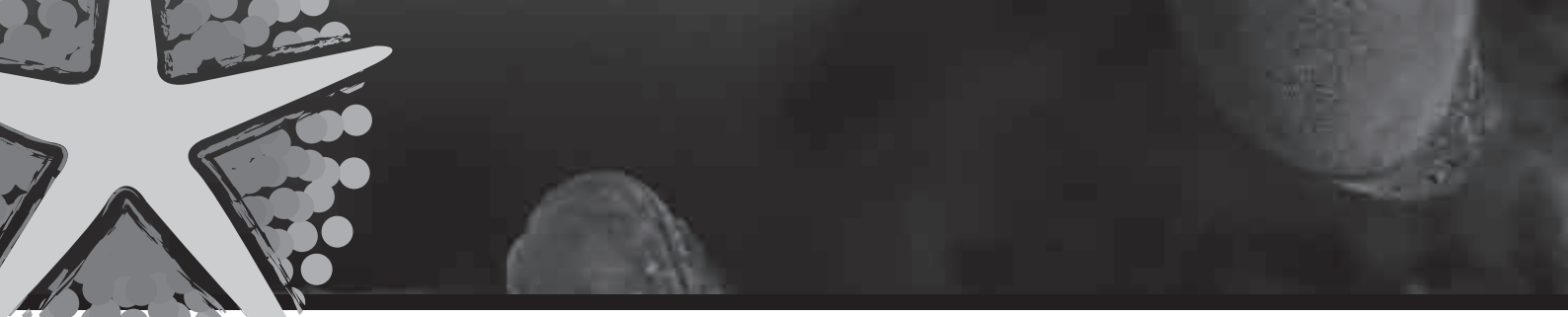
Abstract
Work done during the Node 1 project to investigate the cause of the autumn-winter phytoplankton bloom on the south west WA shelf is presented in this talk. A nitrogen budget indicates that the continental shelf is primarily a recycling system with the supply of dissolved nitrogen from the sediment as the dominant source. In this case hydrodynamic forcing of the sediment nitrogen supply may explain why the phytoplankton biomass increases in the winter. However, evidence that the magnitude of the shelf-bloom is associated with the strength of the Leeuwin Current suggests that the supply of nitrogen from offshore is also important.



Node: 1
Title: Marmion Lagoon hydrodynamics

Author: Graham Symonds
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Abstract
Observations of waves and currents in a temperate reef environment off southwestern Western Australia over a period of one year reveal the relative importance of wind and wave forcing. During periods of low waves linear regression analysis shows alongshore currents seaward and shoreward of the reef line are reasonably well predicted using 1% and 0.5% of the wind speed respectively. However, shoreward of the reef line anomalously strong currents were often observed during periods of light or even opposing winds and the mean sea surface was elevated relative to offshore of the reefs. These anomalous currents and elevated sea level occur during periods of high waves and both are correlated with the root-mean-square wave height seawards of the reefs, similar to what has been observed in coral reef environments. The observations were simulated with the numerical model XBeach which includes radiation stress forcing due to the presence of the waves. The model was also used to examine the dynamics of the wave driven flow in terms of the momentum balance. As on a coral reef, through the surf zone over the reef bottom friction is balanced by the sum of the radiation stress gradient and pressure gradient. Away from the reefs the radiation stress gradients are small and the momentum balance is between bottom friction and pressure gradient.

Node: 1
Title: Marmion Lagoon Biogeochemistry

Author: Jim Greenwood
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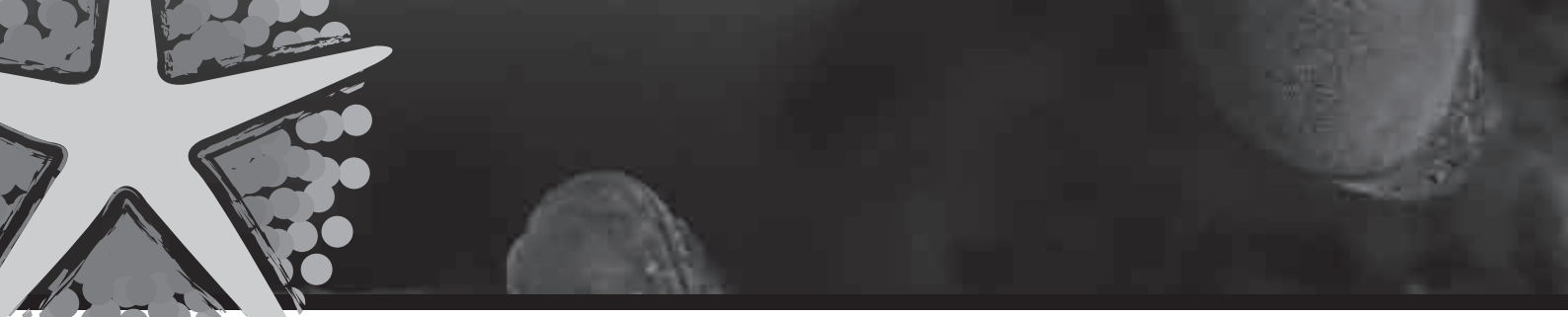
Abstract
During the WAMSI node 1 project the biogeochemistry of Marmion Lagoon has been shown to be characterised by high levels of nitrate in the vicinity of the limestone reef throughout the year. An investigation using a high resolution numerical model to trace the source of this nitrate is presented in this talk. Submarine groundwater discharge and biological mediated nitrification are discussed as possible explanations.



Node: 1
Title: Shelf water retention and alongshore connectivity off the WA coast

Author: Ming Feng
Collaborators: Dirk Slawinski, Lynnath Beckley, John Keesing
Institution: CSIRO, Murdoch University
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Abstract

Retention and dispersal of shelf waters under the influence of ocean boundary currents is crucial to recruitment processes of many coastal species. In this study, a Lagrangian particle tracking method based on an eddy-resolving, data-assimilating, hydrodynamic model is used to study spatial variations of local retention rates and alongshore dispersal of surface waters on the continental shelf off the west coast of Australia. The circulation on the shelf off the west coast of Australia is dominated by the southward-flowing eastern boundary current, the Leeuwin Current, which is interrupted by episodic wind-driven, northward, inshore surface transport during the austral summer, and by mesoscale eddy formations during the austral winter. Low-retention shelf regions tend to experience high alongshore currents, owing to the near-shore influence of the Leeuwin Current, protruding coastal geography, or formation of mesoscale eddies, whereas high-retention regions are sheltered from the direct influence of the Leeuwin Current by coastal geographic features. Alongshore dispersal also exhibits spatial as well as seasonal heterogeneity, with predominantly southward dispersal during the austral winter, and more symmetrical dispersal during the austral summer. Shelf retention and seasonal dispersal are linked with recruitment processes of invertebrate and fish species off the west coast of Australia.

Node: 1
Title: Sediment biogeochemistry across a sediment nutrient gradient

Author: Martin Lourey
Collaborators: John Keesing, Peter Thompson, Tennille Irvine, James McLaughlin, Guy Abell, Doug Bearham, Lesley Clementson, Jim Gunson, Peter Hughes, Fiona Graham and Stan Robert.
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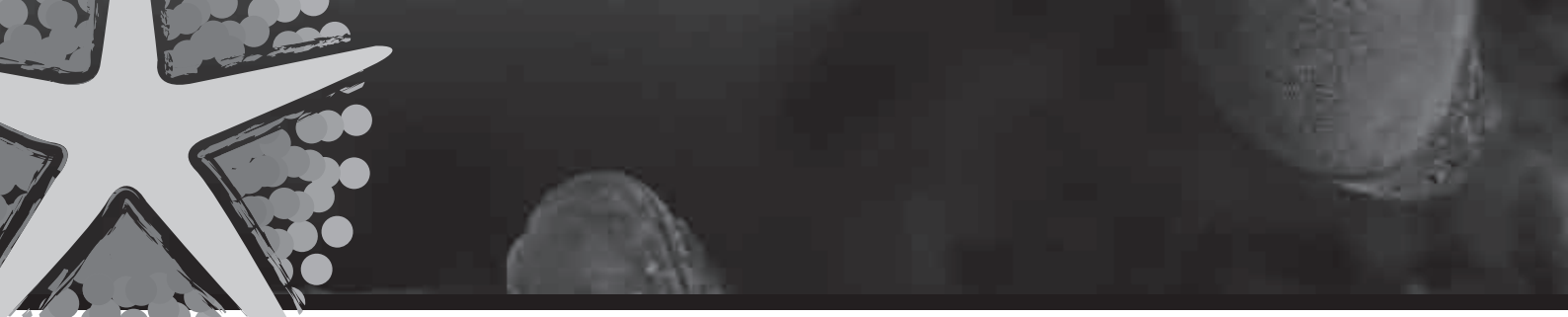
Abstract
Rapid population growth, combined with associated industrial development and urbanisation has placed increasing pressure on the coastal environment in south Western Australia and there is increasing concern about the effects of anthropogenic nutrient discharge. Unfortunately, the effects of nutrients discharged into the Western Australian are poorly understood. Increased nutrient loadings have the capacity to significantly enhance primary production at the continental shelf scale and cause eutrophication plus hypoxia in some ecosystems. We aimed to develop a conceptual understanding of ecosystem responses to forcing factors (primarily anthropogenic nutrient load) with the ultimate aim of improving our capacity to predict the impacts of anthropogenic activities which alter the physical dynamics and level of nutrients in nearshore systems. We suggest sediment nutrient content as a proxy for nutrient enrichment because it is less variable than water column concentrations and likely integrates over time.

We measured a wide range of physical and biogeochemical parameters and a series of ecological and physiological responses across existing sediment gradients in the Perth metropolitan area. Our findings confirmed our view that sediment nutrient levels, amongst other factors, were an important driver of the physiological, biological and ecological dynamics of soft bottom benthic habitats. Generally, enriched sediment habitats (such as we observed at Northern Harbour in Cockburn Sound) display low levels of benthic primary production, high levels of heterotrophic bacteria and sediment community respiration and low levels of infaunal and macrofaunal biomass and diversity. The majority of mean sediment nutrient fluxes encountered outside Cockburn Sound were negative suggesting that consumption of nutrients by MPB out strips supply from the sediments. Positive nutrient fluxes were more common within the sound. For example, ammonium was universally consumed outside Cockburn Sound, in both seasons and in both light and dark experimental treatments. Inside the sound, there was pronounced ammonium release from sediments, particularly in the dark treatments and during summer.



Node: 1
Title: Assessing the role of benthic filter feeders in Marmion Lagoon

Author: Joanna Strzelecki
Collaborators: John Keesing, Jane Fromont, Geordie Clapin, Christine Hanson, Julia Philips
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Abstract

Benthic filter feeders have an important role in marine ecosystems by modifying substrate, providing habitats for a wide assortment of organisms, influencing carbon flow, facilitating growth of seagrass and controlling red tides. They are also an important part of food webs linking the benthic and planktonic system. They influence the level of phytoplankton and other suspended particles in the water column and enhance nutrient concentrations near the reefs.

In coastal marine areas suspension feeders form dense populations and the nearshore reefs and seagrass beds in Marmion Lagoon are no exception harbouring high cover of sponges and ascidians. Biomass of filter feeders in Marmion Lagoon has been surveyed in different habitats in 1993 and 1994 by CSIRO and it is the most detailed survey of these organisms up till today. Reef habitats supported more filter feeders than sand or seagrass and inshore reefs supported more biomass comparing to offshore. Within reefs turfing algae had more biomass than kelp or *Sargassum* spp covered reefs. We measured *in situ* filtration of common sponges and ascidians in Marmion Lagoon.

Sponges' filtration rates ranged from 0.0004 for Callyspongiidae A to 0.4 l-1 s-1 l for Mycalidae. Ascidians' filtration rates ranged from 0.012 to 0.12 l-1 s-1 l and were significantly more variable than pumping rates of sponges. Both sponges and ascidians excrete ammonia as their waste product and can be an important nitrogen source on the reefs. In our study we have shown higher nitrite/nitrate and ammonium levels near filter feeders and quantified production rates of nitrogen.

This project provided first estimation of *in situ* filtration of common sponges and ascidians in Marmion Lagoon. It quantified removal of particulate organic matter and selectivity by abundant organisms of local reefs. In oligotrophic waters of Western Australia coast bacteria plays a central role in the food web structure and we explored the role of macrobenthic invertebrates feeding on bacteria in regulating the structure of the microbial food web. This project contributed to understanding of inorganic nitrogenous fluxes and microbial transformations of organically bound nutrients. It provided a method for non destructive quantification of filtering rates by sponges and ascidians that can be used in future monitoring of filtering activity. In view of ecological importance of filter feeders this information has relevance to management of Marmion Lagoon particularly given its proximity to the metropolitan area and pressures associated with human use.

Node: 1
Title: Kelp patch dynamics

Author: Russ Babcock
Collaborators: Damian Thomson, Mat Vanderklift, Fiona Graham, Doug Bearham
Institution: CSIRO Marine and Atmospheric Research
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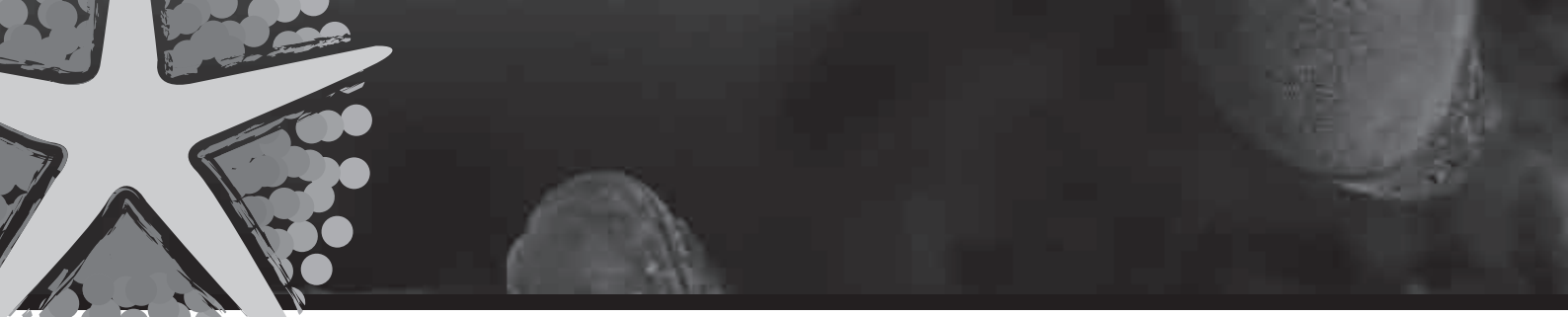
Abstract

Ecologically sustainable management of resources requires the ability to rapidly address the current state of resources as well as key ecological processed which maintain these resources. Increasingly, resource managers also require information on the relative importance of physical versus biological processes in order to predict how ecosystems may respond to environmental variability including a changing climate. In order to better characterise the south west Australian marine coastal and shelf ecosystem structure and function, and enhance our shared capacity to understand, predict and assess ecosystem response to anthropogenic and natural pressures we assessed the relative importance of physical forcing and ecological interactions among key functional groups in determining patterns of spatial mosaics in benthic habitats.

The project focused on the habitat dynamics of temperate algal communities on reefs off Western Australia. These algal communities display a complex mosaic of different algal assemblages, or habitat types, broadly characterised as either canopy or gap habitats. This mosaic structure has a strong influence on the overall biodiversity of rocky reefs in temperate south west Australia. Changes in this pattern and the relative proportion of the two habitat types will therefore have profound implications for the biodiversity and productivity of coastal marine ecosystems in the region. In order to understand the dynamics of this habitat mosaic structure, the project employed three complimentary approaches.

Mosaics of habitat dominated by canopy-forming macroalgae and canopy-free (open-gap) habitat are prominent features of temperate subtidal reefs, with the proportion of reef occupied by canopy forming algae ranging between 40% and 60% based on diver transects. However, the persistence of this mosaic structure and mechanisms underlying this pattern are not well understood. We described patterns in the proportion of reef covered by each of these habitats, and the length of patches of each habitat, at 20 sites encompassing a gradient in wave exposure in south-western Australia. Our aims were to characterise patterns, and the strength of associations with potential influences, in order to develop models of habitat mosaic generation and maintenance. Modelled seabed orbital velocities explained approximately 35% of the variation in the length of open-gap patches with less canopy cover at higher wave exposure sites. This observation supports the hypothesis that waves create open-gaps by dislodging canopy algae. Herbivorous damselfish (*Parma spp.*) were 5.6 times more likely, and the sea urchin *Heliocidaris erythrogramma* was 20 times more likely, to be encountered at sheltered inshore sites than at exposed sites further from shore. *Parma* were 8.2 times more likely to be found in open-gap habitat. However, there was no relationship between the occurrence of either herbivore and the proportion of open-gap habitat among sites. These observations do not support a hypothesis that grazing by herbivores creates open-gaps. Massive sponges were three times as likely to be found in open-gap habitat, and hard corals were 91 times more likely to be encountered in open-gap habitat. The strength of these associations suggests that canopy algae might negatively influence sessile invertebrates. Further, the large size and likely old age of sessile invertebrates, particularly hard corals, indicates that patches of open-gap habitat can persist for decades. The patterns observed suggest that wave-induced disturbances create open-gaps and that these gaps are persistent features of temperate reefs.

The results of artificial clearance disturbances indicate that Gap habitat macroalgal assemblages are strong competitors for space and that Canopy is slow to establish, with most canopy clearances remaining as Gap habitat after 3 years. However where returns to canopy habitat were observed, they were more likely to occur when clearances were within or adjacent to Canopy habitat. Modelling of habitats using observed probabilities of transitions in habitat state indicated that in undisturbed habitats the average residence time (longevity) of Gaps was 3.7 yrs and for Canopy 2.8yrs, while in disturbed habitats average Gap residence time was 12 years, of the same order as the average estimated age of coral populations within gaps, while with Canopy habitats had much shorter residence times of 2.4 yrs. When Canopy habitats were differentiated into *Ecklonia* and *Sargassum*, the two principal canopy forming taxa, the residence times were 6 and 1.6 yrs respectively and Gap residence times remained unchanged. Projections of proportional composition of the habitat mosaic indicate that, because of the asymmetrical response to disturbance, any increase in the frequency of gap creation is likely to have long term and disproportionate negative impacts on overall canopy cover.



Node: 1

Title: Larval fish assemblages and particle back-tracking provide insight into Eastern Indian Ocean boundary current processes

Author: Beckley, Lynnath E.[1]

Collaborators: David Holliday[1], Evan Weller[2], Natalie Millar[1], Maria-Pilar Olivar[3], Ming Feng[2], Dirk Slawinski[2] and Peter A.Thompson[2]

Institution: [1] School of Environmental Science, Murdoch University
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[3] Institut de Ciences del Mar, CSIC, Spain

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Synoptic examination of the Leeuwin Current (LC) system along the Western Australian continental shelf and adjacent ocean (22°S–34°) during the late austral autumn of 2007 was accompanied by a depth-integrated, bongo-net survey of the associated larval fish assemblages. The temperature and salinity signature of the LC experienced substantial modification as it flowed south; surface temperature of the LC decreased by ~5.25°C while surface salinity increased by ~0.72 psu. Comparison of these empirical data with the Bluelink re-analysis product (based on the hydrodynamic model OFAM) revealed the model to provide a good representation of the oceanography of the LC system. Larval fishes were highly diverse comprising >200 taxa from 114 neritic and oceanic teleost families. Two-factor PERMANOVA indicated significant structuring of larval fish assemblages both latitudinally and across isobaths with a significant interaction term. MDS ordination of larval fish assemblages showed clustering of northern inner shelf stations (22ºS - 28ºS) with that of a developing meso-scale eddy at the 27ºS oceanic station.

Results from particle back-tracking indicated that, in the previous month, this eddy had strong connection with surface shelf waters from as far north as Northwest Cape at ~22ºS. Larval fish assemblages at shelf break and oceanic stations throughout the study area had high similarity and clustered with inner shelf stations south of 29ºS indicative of geostrophic inflow, entrainment of Subtropical Water and mixing of regional water masses from the continental shelf. Although the particle back-tracking uses passive kernels, and larvae of marine fishes are known to have complex behavioral and physiological capabilities which can influence their transport, this study has demonstrated broad-scale advection of planktonic biota, both across the shelf, and alongshore in the Eastern Indian Ocean.

Node: 1
Title: DIVE - Data Interrogation and Visualisation Environment

Author: Gary Carroll
Collaborators: Uwe Rosebrock
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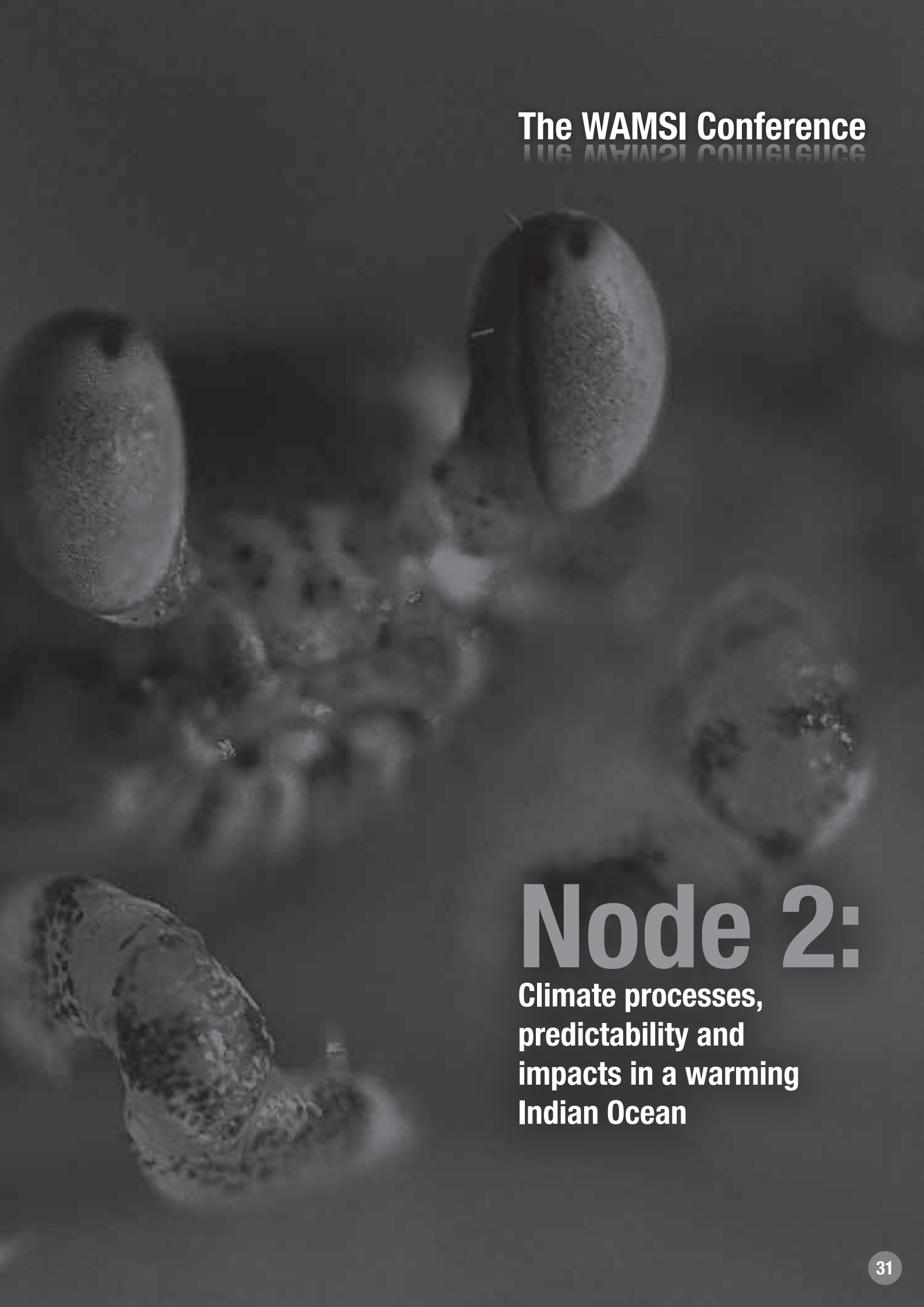
DIVE is a data visualisation and interrogation tool developed for, but not limited to, geographically localised, temporally and spatially varying data. It specifically targets the visualisation of multidisciplinary data and multidimensional data. DIVE is Java-based and runs on Windows, Linux and Mac OSX computers.

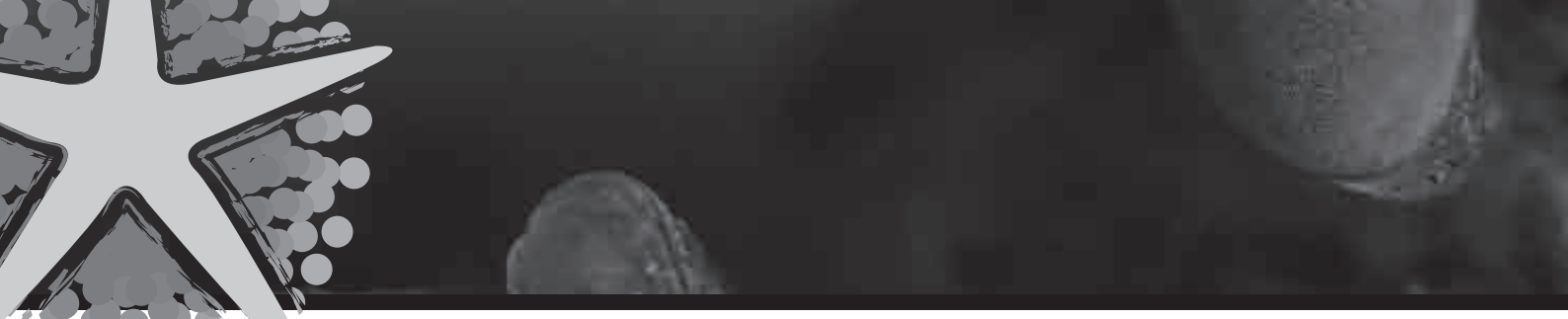
DIVE can source data from hydrodynamic and biogeochemical modelsas curvilinear, rotated or rectangular grids; observational data from underway vessels, gliders and CTD; as well as remote-sensing data such as satellites and aircraft. DIVE reads a variety of formats including NetCDF(CF 1.x and several in-house CMAR formats) and HDF files.

DIVE is controlled via an intuitive graphical user interface. Data from numerous sources may be plotted simultaneously, e.g. model output and field measurements. Visualisations may be easily explored in 4 dimensionsand output may be rendered as surface or vector plots, time series, vertical profiles and arbitrary horizontal or vertical cross-sections. DIVE can export to standardimage file formats and produce animations.



Node 2:

Climate processes, predictability and impacts in a warming Indian Ocean



Node: 2
Title: Node 2 Leader's Overview: Climate variations across time scales

Author: Ming Feng
Collaborators: Harry Hendon, Richard Brinkman
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Abstract
The objective of the WAMSI Node 2 is to understand and predict large scale variation and change of ocean-climate, its impact on the continental shelf, and to inform decision making in WA agencies that have to address vulnerability to climate variation and change. This objective is achieved through three inter-related research projects that cover climate variability from intraseasonal, seasonal, and interannual time scales to decadal and long term trends.

In Project 2.1, we have looked at the ability to predict the large-scale drivers of variability of the marine environment of Western Australia with a focus on the Leeuwin Current. The focus has been on seasonal predictions from 1-9 months. Providing seasonal predictions of the variations of the Leeuwin Current for the upcoming seasons has great potential benefit for improved management of the WA marine environment. The main forecast tool that we used was the BoM coupled model seasonal forecasting system called POAMA. This project has demonstrated both the utility of the existing POAMA system for seasonal predictions relevant to the WA marine environment and the limitations of the system that will need further development in order to provide more useful and accurate predictions. It has also increased the understanding of what drives variations of the WA marine environment and, more generally, in the Indian Ocean, especially focusing on how the El Niño phenomena in the Pacific is communicated to the WA marine environment and on the Indian Ocean Dipole. This research underpins future development of the POAMA seasonal forecast system, especially the need to eliminate systematic model bias and the need to properly simulate El Niño and its remote impacts.

In Project 2.2, we have focused on the climate impact on one of the key ocean circulation systems of Western Australia, the Leeuwin Current system. The Leeuwin Current is highly connected to the marine environment, fisheries, offshore industries, and recreational lifestyle of Western Australia. In the project, we have enhanced our understanding the mechanism of the interannual temperature variability off the lower west coast. Using field observations and numerical modelling, the project has improved our knowledge of the Leeuwin Current eddy's role in nutrient and fish larvae transport off the west coast. The project has also detected the multi-decadal strengthening trend of the Indo-Pacific circulation and the Leeuwin Current since early 1990's, which has resulted in some unprecedented strong Leeuwin Current events. The research results from this project have significantly improved our knowledge of natural variability and future changes of the Leeuwin Current system and provide useful tools to manage marine ecosystem and fisheries of Western Australia. In the project, we have assessed the climate change impacts on the marine environment off Western Australia. In addition, we have used a global ocean circulation model, the BLUElink model, to downscale climate change scenarios for ocean boundary current surrounding Australia. This project has not only underpinned the climate impact downscaling research in the Ningaloo Reef in WAMSI project 2.3, it will also develop the basis for future climate change research along the western coast, such as the National Climate Change Adaptation Research Facility's Western Australia fisheries climate adaptation project.

Project 2.3 has investigated the ocean current dynamics that influence the Ningaloo Reef tract, using both field observations and a suite of numerical models to downscale coarsely resolved global ocean circulation models. Offshore from Ningaloo, the Leeuwin Current gains definition at North West Cape, and flows southwards along the continental slope transporting warm low-salinity tropical water. Closer inshore, southerly winds create the seasonal Ningaloo Current; an intermittent coastal counter current inserted between the poleward flow of the Leeuwin Current and the fringing reef front. This project has investigated how the interaction of these two currents control the thermocline depth and upwelling along Ningaloo Reef under contemporary and future ocean conditions, by using future predictions from a global ocean circulation models. This work has increased our understanding of the local ocean dynamics along Ningaloo Reef, and provided an indication of how these dynamics may change in the future.

Node: 2

Title: Understanding and Predicting Impacts of the Indian Ocean Dipole

Author: Harry H. Hendon
Collaborators: Maggie Zhao
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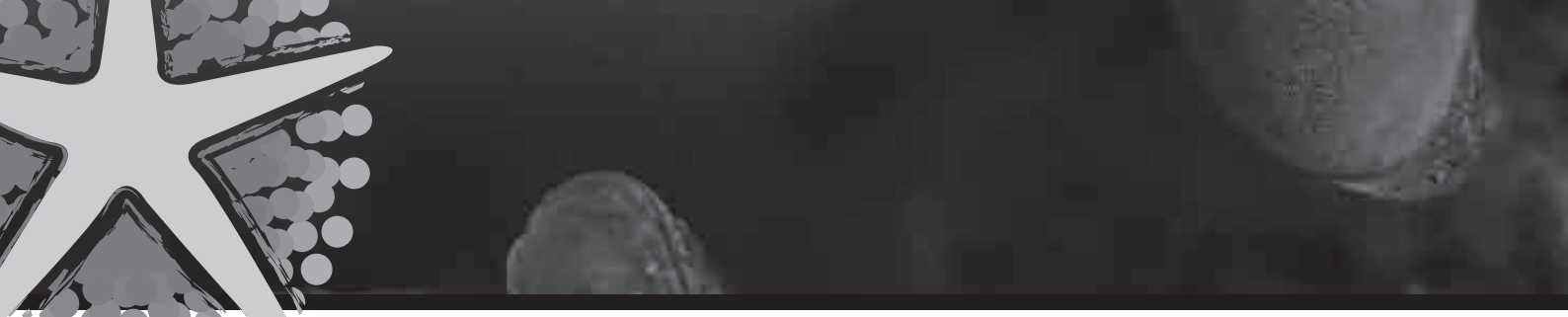
Email: hhh@bom.gov.au

Abstract

There is a growing appreciation for the role of the tropical Indian Ocean in global climate variability. In particular, the Indian Ocean Dipole (IOD) is now understood to be a direct source of global climate variability for the surrounding regions but it also plays a primary role in the pathway of the teleconnection of El Niño/Southern Oscillation into extratropical latitudes of the southern hemisphere, especially across southern portions of Australia. This teleconnection is via a generation of Rossby wave trains by convective heating fluctuations in the eastern and western poles of the IOD. The ability of seasonal forecast models to predict the teleconnections of the IOD is assessed. We compare predictions from the Bureau of Meteorology's dynamical season prediction model, Predictive Ocean Atmosphere Model for Australia (POAMA) with predictions from ENSEMBLE Project. We show a range of ability by these forecast models to simulate and predict the teleconnection driven by the IOD. Errors in this teleconnection, which severely limit the ability to predict climate variations across southern Australia associated with the occurrence of the IOD and ENSO, appear to stem primarily from biases in the tropical convective variations associated with the IOD. Improvement of both the mean state and variability of rainfall in the tropical Indian Ocean should thus lead to improved ability to predict extratropical climate.



Node: Node 2

Title: Impact of assimilating salinity on the simulated mean state and variability in a coupled seasonal forecast model

Author: Maggie zhao
Collaborators: Harry Hendon, Yonghong Yin, Oscar Alves
Institution: CAWCR, BOM
Email: m.zhao@bom.gov.au

Abstract

An improved ocean data assimilation system has been developed to provide improved ocean initial conditions for seasonal climate prediction using the BoM POAMA forecast model. Importantly, the new improved analyses better depict salinity. We show, based on a series of seasonal climate hindcasts for the period 1982-2008, that the new ocean analyses result in improved prediction of El Niño, which is the key driver of interannual variability of the Leeuwin Current. We further show that the mean differences between the old and new ocean analyses lead to mean differences in the simulated El Niño variability that last then entire 9 months of the forecast. We show that it is primarily the mean difference in subsurface salinity that is the main contributor to the difference in simulated El Niño variability: the erroneous depiction of subsurface salinity in the old analyses leads to a rapid adjustment of density that then causes large, long-lasting compensating temperature changes that affect the stability of the coupled system. The implications of this work are that proper initialization of subsurface salinity is crucial for extended range (out to 1 year) prediction of El Niño and that subsurface salinity variations may be a potential source of multi-year predictability.

Node: 2
Project: Seasonal and intra-seasonal variability along Australia's NW and Northern Shelves

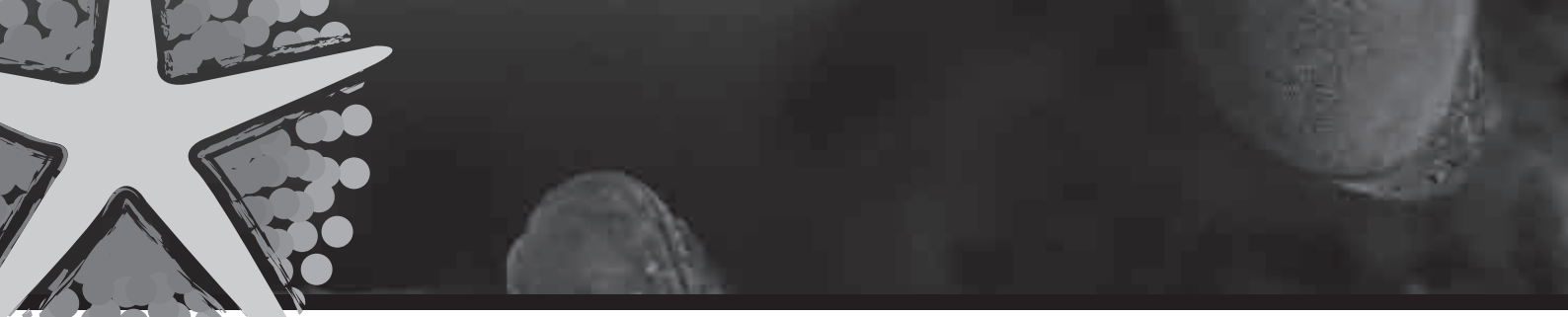
Author: Andreas Schiller
Collaborators: Ming Feng, Chaojiao Sun
Institution: CSIRO
Email: Andreas.Schiller@csiro.au

Abstract

The Timor Sea, Arafura Sea, associated Shelves and the Leeuwin Current are central to some of the big issues facing the region: climate variability and change; sustainable development coupled to economic growth; regional, food and energy security; and health and wellbeing of the populations living along their coastlines. Increasingly, biophysical and ecosystem models are being used to (a) simulate present and future scenarios of regional-scale and coastal environments in this region and (b) to provide information to policy makers and stakeholders to enable them to make informed decisions about responses to the environmental challenges faced in this region. In this presentation I will discuss some of the seasonal-to-internannual large-scale features which must be properly observed, understood and modelled to allow accurate environmental planning and decision making on all relevant spatial scales.

The recent INSTANT measurements in the Indonesian archipelago revealed a broad spectrum of time scales that influence Indonesian Throughflow (ITF) variability, from intraseasonal (20–90 days) to interannual. The different time scales are visible in all transport and property fluxes and are the result of remote forcing by both the Pacific and Indian Ocean winds, and local forcing. The INSTANT observations in combination with output from the Bluelink ocean reanalysis provide a comprehensive picture about the propagation of intraseasonal variability (ISV) in the ITF region. The reanalysis and observations reveal that deep-reaching subsurface ISV in the eastern Indian Ocean and ITF is closely linked with equatorial wind stress anomalies in the central Indian Ocean. Having traveled more than 5000km in about 14 days, the associated Kelvin waves can be detected as far east as the Banda Sea. ISV near the Straits of Ombai and Timor is also significantly influenced by local wind forcing from within the ITF region. At the INSTANT mooring sites the ocean reanalysis agrees reasonably well with the observations. Intraseasonal amplitudes are about ±1.0 ºC and ±0.5 m/s for potential temperature and velocity anomalies. Seasonal maxima of northeastward (southwestward) volume transports on Australia's northern shelf are almost symmetric and exceed 106 m^3/s in February (June). The associated seasonal cycle of vertical upwelling from June to August south of 8.5 ºS and between 124 ºE and 137.5 ºE exceeds 1.5 x 106 m^3/s across 40 m depth. During El Nino events, combined anomalies from the seasonal means of high regional wind stresses and low inter-ocean pressure gradients double the northeastward volume transport on the North Australian Shelf to 1.5 x 106 m^3/s which accounts for 20% of the total depth-integrated transport across 124 ºE and further reduce the total transport of the Indonesian Throughflow.

To be useful, regional biophysical and ecosystem models and analyses rely on accurate observations and simulations of features such as those described above. Efforts to improve this "seamless" observing, simulation and prediction capability in WA continue as part of, e.g., IMOS and BLUElink, but require close interactions with and support from WAMSI researchers.



Node: 2

Title: Strengthening of the East Australian Current and weakening of the Leeuwin Current in a warming climate: Results from dynamical downscaling

Author: Chaojiao Sun
Collaborators: Ming Feng, Richard Matear, Matthew Chamberlain, Peter Craig, Ken Ridgway, Andreas Schiller
Institution: CSIRO
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Abstract

Ocean boundary currents are poorly represented in existing climate models, in part due to insufficient resolution to resolve these narrow jets. As a result, there is limited confidence in the response of boundary currents to climate change projected by these models. To address this issue we use an eddy-resolving ocean model around Australia, the Ocean Forecasting Australia Model (OFAM), to provide downscaled regional ocean protections, based on bias-corrected output from the CSIRO Mk3.5 climate model under the A1B emissions scenario for the 2060s. Mk3.5 captures a number of robust changes that are common to most coupled climate models and are consistent with observed changes. These include the weakening of the equatorial Pacific zonal wind stress and strengthening of the wind stress curl in the Southern Pacific, which are important for driving the boundary currents around Australia.

For reference, a “current-climate” high-resolution ocean state is obtained by forcing OFAM with typical air-sea fluxes in the 1990s, based on output from the ERA40 reanalysis. To account for some of the spatial biases in the Mk3.5, the 2060s output is bias-corrected prior to using it for downscaling. The current speed, seasonality, and volume transports of the two major boundary currents around Australia, the Leeuwin Current (LC) and East Australian Current (EAC), as well as the Indonesian Throughflow (ITF), show much greater fidelity to the observations in the downscaled model. Between the 1990s and the 2060s, the downscaling with the OFAM model simulates a 15% reduction in the LC transport, a 20% increase in the EAC transport, and a 20% decrease in the ITF transport. Although the direction of change projected by the high-resolution model are usually in agreement with Mk3.5, the OFAM simulation provides important regional details and differences for studying the impact of climate change on ecosystems. The changes in the LC and EAC are also consistent with observed trends over the past several decades, and with changes in wind-driven circulation derived from Sverdrup dynamics.

Node: 2
Title: Downscaling future ocean scenarios to Ningaloo Reef

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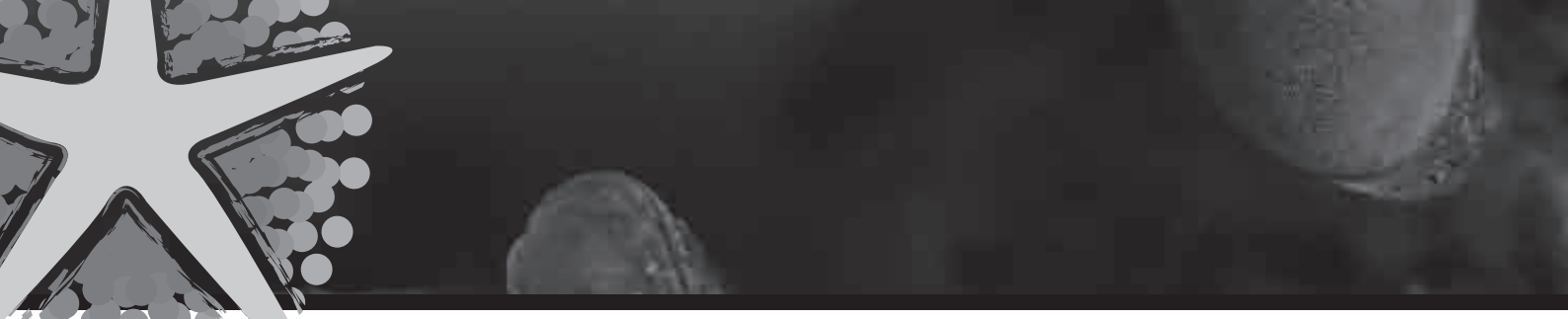
Downscaling future ocean scenarios to Ningaloo Reef

Climate change, in the form of higher sea temperatures, is a major threat facing coral reefs. As sea temperatures rise and exceed the long-term seasonal average for more than a few weeks, the symbiotic relationship between the coral host and internal micro-algae (zooxanthellae) breaks down in a process known as coral bleaching. Research on the GBR has shown that hydrodynamic flows and turbulent mixing of the water column can significantly lower the risk of bleaching at significant spatial scales. Thus, generating knowledge on likely extent and frequency of coral bleaching events requires future knowledge of both local hydrodynamics and ocean thermal structure.

This WAMSI project has downscaled future ocean climate into the Ningaloo Reef system and evaluated realistic scenarios of future climate change at spatial scales relevant to reef ecosystems. This project has investigated the ocean current dynamics that influence the Ningaloo Reef tract, using both field observations and a suite of numerical models to downscale coarsely resolved global ocean circulation models. Offshore from Ningaloo, the Leeuwin Current gains definition at North West Cape, and flows southwards along the continental slope transporting warm low-salinity tropical water. Closer inshore, southerly winds create the seasonal Ningaloo Current; an intermittent coastal counter current inserted between the poleward flow of the Leeuwin Current and the fringing reef front. This project has investigated how the interaction of these two currents control the thermocline depth and upwelling along Ningaloo Reef under contemporary and future ocean conditions, by using future predictions from a global ocean circulation models delivered through WAMSI Node 2 Projects 2.1 and 2.2. This work has increased our understanding of the local ocean dynamics along Ningaloo Reef, and provided an indication of how these dynamics may change in the future.



Node: 2 and 4

Project: Warming trends of ocean temperatures off the Western Australian coast and implications for fisheries

Author: [1]Nick Caputi
Collaborators: [1]Alan Pearce, [1]Rod Lenanton, [2]Ming Feng
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Abstract

Key environmental trends affecting fish stocks of Western Australia (WA) include: (a) increasing frequency of ENSO events; (b) variations in strength of the Leeuwin Current; (c) increase in water temperature off the lower west coast; (d) increase in salinity; (e) change in frequency and location of storms affecting the lower west coast; and (f) change in frequency of cyclones (and rainfall) affecting the north-west. One of the areas of greatest increase in surface sea temperatures (SST) in the Indian Ocean over the last 50 years has been off the lower west coast of WA. SST trends at coastal sites and global SST data showed a strong seasonal variation, with most of the increases (0.02-0.035ºC per year) occurring over autumn-winter with little increase (<0.01ºC per year) in spring-summer. The warming trend results in a change to the seasonal temperature cycle with a delay in the peak temperature during autumn between the 1950s and 2000s of 10-20 days. While the long term trend of the SST is likely to be the result of local air-sea exchanges, the year to year temperature variations are more determined by the Leeuwin Current heat transport from the north, as determined from an ocean heat budget analysis. The unprecedented warming event off the WA coast during February and March 2011 was due to an extremely strong La Niña event which resulted in a near-record strength of the Leeuwin Current and heat transport, which are superimposed on the long-term warming trend off the coast. The warming event, and the long-term trend, has strong implications for the marine environment off WA.

Fisheries data may be a cost-effective way of assessing changes in the distribution and relative abundance of species. These long-term data collections are cost effective compared to setting up separate monitoring programs. They include: (a) logbook catch and catch rate data; (b) research staff going onboard commercial vessels to monitor the catch; and (c) standardized research survey of stocks. A number of oceanographic and meteorological data sets from both historical and current data sources have been compiled. The western rock lobster fishery has long-term time series (40 years) on a biological variables and fishery-independent estimates of recruitment, puerulus settlement, which makes it one of best candidates to study climate change effects on a fishery in Australia. Climate change effects identified include increasing water temperatures effect on a decrease in size at maturity and migrating lobsters from shallow to deep water. The size of the migrating lobsters is significantly related to the water temperature about the time of puerulus settlement (4 years previously). Some of these changes (e.g. increasing frequency of El Niño events) may have negative implications on the fishery but others such as increasing water temperature may have some positive influence. Environmental factors affecting fish stocks and possible climate change implications were also examined for other stocks including prawns, scallops, blue swimmer crabs, pearl oysters, tailor, dhufish and whitebait. The changes in some of the biological parameters of the rock lobster stocks have been included in the population dynamic model of the fishery. Long-term changes in the abundance and distribution of fish stocks require an appropriate management response to ensure sustainability. These case studies highlight the value of long-term time series in fisheries and environment in assessing climate change effects on fisheries.

Node: Node 2

Title: Incorporation of larval fishes into a developing anti-cyclonic eddy of the Leeuwin Current off south-western Australia

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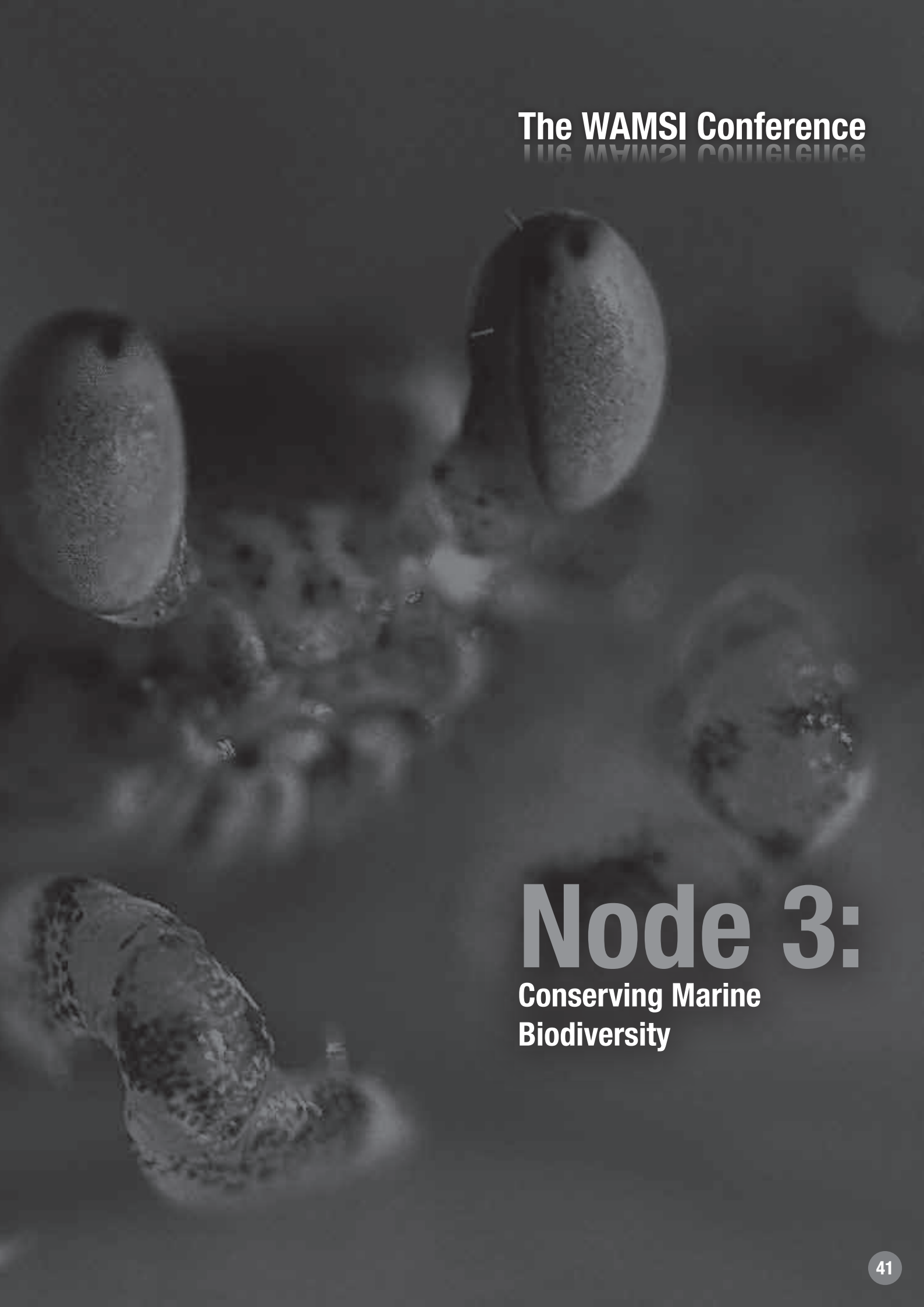
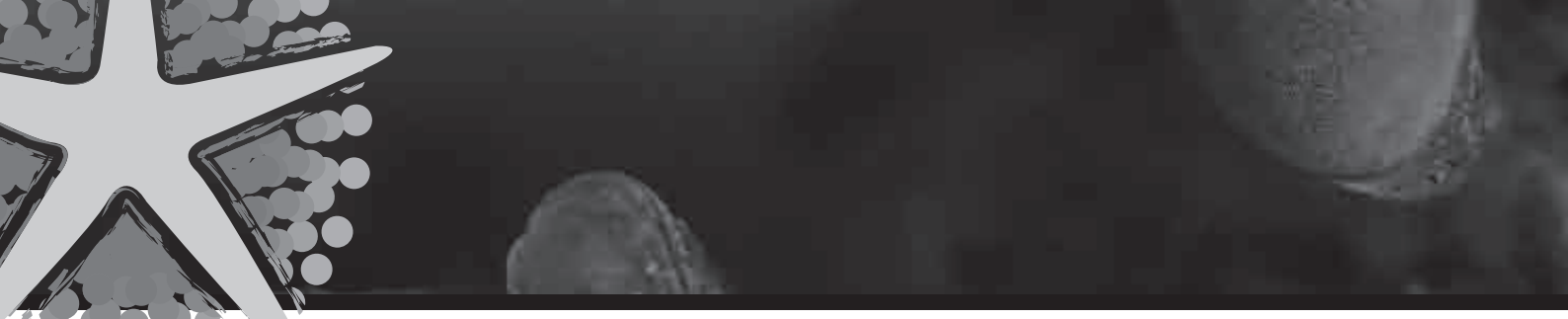
This study, which contributed to the objectives of WAMSI Node 2, examined the influence of Leeuwin Current eddies upon the transport and fate of fish larvae off south-western Australia. Larval fish assemblages within the study region were structured by location (shelf, eddy and oceanic) and water mass. The larval fish assemblage within the eddy was significantly distinct from that characterising the surrounding oceanic water. The eddy assemblage, which was comprised largely of larvae of oceanic meso-pelagic fishes (especially *Diaphus* spp. and *Vinciguerria* spp.) and less abundant neritic taxa, reflected its Leeuwin Current, shelf and oceanic source waters. The occurrence of neritic taxa in the eddy confirmed the hypothesis that these larvae were incorporated as it developed in proximity to the shelf break. The significantly larger larval size of temperate neritic taxa (e.g. *Sardinops sagax, Engraulis australis*) in the eddy compared to the shelf suggests that these larvae were transported from the shelf adjacent to the developing eddy. The occurrence of tropical neritic taxa (e.g. Acanthuridae, Lutjanidae, Pomacentridae) highlighted the LC as an important transport route to higher latitudes. Coupling depth-integrated and depth-stratified sampling of larval fishes with the trajectories of Lagrangian drifters provided insight into how larval fish assemblages changed during development of the eddy.



Node 3:
Conserving Marine Biodiversity



Node: 3
Project: The Ningaloo Research Program: An overview

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Abstract

In 2005 the Western Australian Government allocated $5M for a program of marine research to support the management of the Ningaloo Marine Park. The Government funding was administered through the Western Australian Marine Science Institution and, with significant co-investment from the Australian Institute of Marine Science, CSIRO, local universities and industry, a research program of around $30-40M was developed around the above broad objective. Over 150 projects have been undertaken over the past 5 years involving over 100 scientists and support staff. Based on the research and monitoring strategies outlined in the Ningaloo Marine Park management plan approved by the State Government in 2005, the research projects have produced a significantly greater understanding of the marine biodiversity in the park and the benefits and potential impacts of current and projected human usage. This enhanced knowledge base will directly inform current and future planning and management of Ningaloo Marine Park.

The presentation will briefly outline the history, major components and outcomes of the Ningaloo Research Program.

Node: 3

Title: CSIRO Collaboration Cluster: Reef use, biodiversity and socio-economics for integrated management strategy evaluation of Ningaloo

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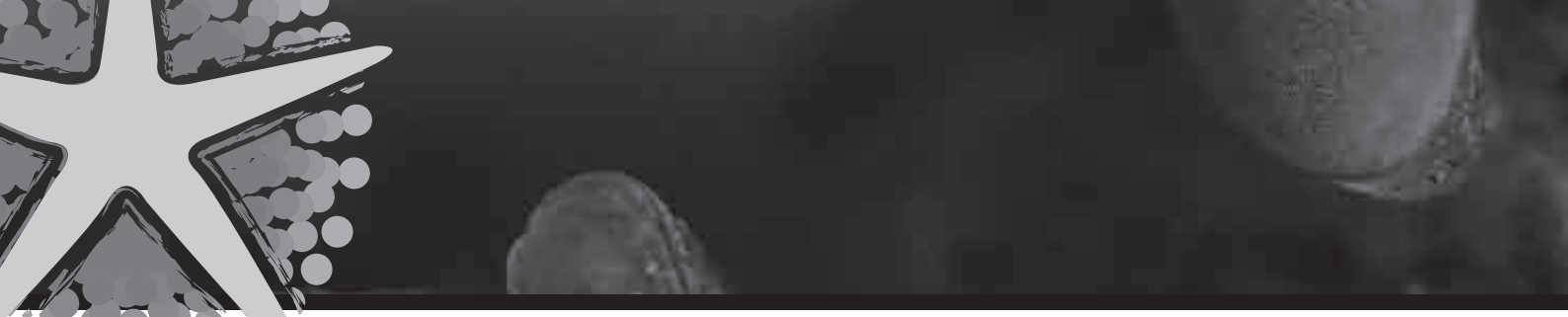
Abstract

The Ningaloo Cluster was developed following the commitment by the WA government to fund WAMSI research on marine biodiversity at Ningaloo. The research in the Cluster, funded by the CSIRO Flagships Collaboration Fund, was designed to complement the WAMSI research and has focused on gaining knowledge of the bathymetry and habitats of the lagoon, human use of the reef and adjacent areas, evaluating options for tourism in the region and investigating the socio-economics of the region. In addition to this research, a major component of the research was the development of models to synthesise and integrate information from all the research carried out at Ningaloo. The models have enhanced our understanding of how the system functions and increased our ability to make predictions about the future condition of the system under different management options. This research has involved collaborations among researchers from a wide range of disciplines and research organisations, including Universities (Murdoch, Curtin, University of Western Australia, Edith Cowan, Australian National University and the University of Queensland), the Sustainable Tourism CRC and CSIRO. It has been successful in attracting additional funding from two sources: 1. BHP-Billiton, coordinated by the Australian Institute of Marine Science, to obtain high-resolution spatial data (Hyperspectral data) on the bathymetry and habitats of the lagoon, and 2. The Sustainable Tourism CRC, to develop a destination model for tourism in the region, with general applicability to other regions. These data and models have enhanced our ability to plan and evaluate different development and management scenarios for the region. Research in the Cluster has been closely coordinated with WAMSI Node 3 research, resulting in many mutual benefits e.g. joint symposia on Ningaloo research, a coordinated program for communication and transferring knowledge of the Ningaloo research and training in the potential application of the models for planning in the region.



Node: 3
Project: Knowledge transfer

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Abstract

The real success of an applied research program that seeks to underpin or support management activities relies on the degree to which new information is needed, made accessible to and used by natural resource managers. The key objective of WAMSI Node 3 is to provide a better scientific underpinning for the management of Ningaloo Marine Park. As such, the Department of Environment and Conservation in its roles as leading Node 3 and as the agency with direct responsibility for the management of Ningaloo Marine Park, has invested significant effort into ensuring that knowledge transfer and uptake have been embedded in the Node 3 science plan. A framework to enhance knowledge transfer was developed and trialled through the Ningaloo research program. This process has addressed the overriding issues of communication and data management that are critical to successful knowledge transfer by developing dialogue and interaction between researchers and end users (i.e. marine park planners and managers) and ensuring that research products will be understandable and available for direct application.

The presentation will briefly outline the process that was employed through Node 3 to address knowledge transfer and uptake along with the recognition and incorporation of external research, complementary to the Node 3 science plan. So far we have taken huge strides in our understanding of Ningaloo reef and the processes that support and impact upon it and this information is reaching the audiences that can use it. However, the real value of knowledge transfer and uptake will be appreciated over the coming years as science is used to support management actions and decisions both in the Ningaloo region and further afield in the WA marine environment.

Node: 3
Project: Near reef oceanic processes and nutrient dynamics

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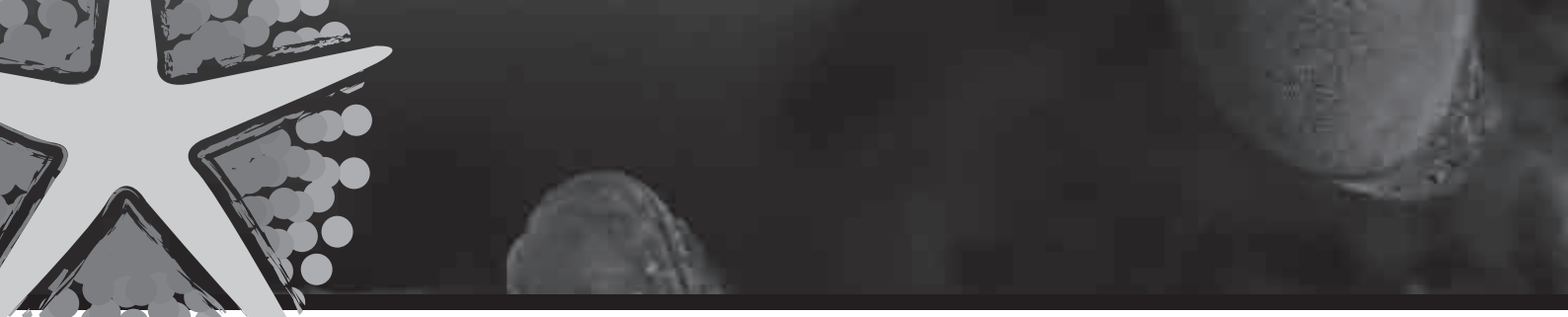
Abstract
We aimed to quantify the supply of food supplied as planktonic particles to the coral community at Ningaloo Reef. Our objectives were to determine the sources of food particles and dissolved nutrients delivered across the reef by the regional oceanography, as well as tracking ocean particle and nutrient sources into the coral reef food web via biomarkers. To achieve our objectives, we conducted a detailed field study at a field site at Sandy Bay, Cape Range National Park. The project consisted of reef-based sampling to assess the local particle flux from the reef front to the lagoon, as well as changes in particle concentrations across the reef top. Within the reef, water column sampling of biogeochemical parameters was conducted along a dominant cross-reef flow path identified in 2007 and described in Wyatt et al. (2010). We documented significant uptake of phytoplankton chlorophyll *a*, (chl *a*)and particulate nitrogen by the reef. However, particulate organic carbon flux (POC) was complicated by significant autochthonous input, likely source from reef photosynthesis. Initial results also suggest that dissolved organic nitrogen sources have the potential to make a major contribution to reef nutrition. The inorganic nutrient sources were highly variable with season outside the reef; our analysis suggests that very rapid transformations (e.g., nitrification) occur on the reef front and reef flat, such that the bacterial production rates in the benthos are likely to be extremely high (Wyatt et al., submitted). While this is beyond the scope of our study, we believe this to be an important potential control on reef biogeochemical processes. The trophic transfer of nutrients to reef fish and other reef organisms is currently under investigation via isotopic analyses; preliminary results suggest that the fractionation of ^{15}N for reef fish may be significantly different than expected from the literature (Wyatt et al., in review). Coral calcification rates as measured via oxygen fluxes within the control volume were found to be typical of Indo-Pacific reefs.

The day-to-day variability in particulate nutrient supply was high in November, and we conclude that the autumn bloom period (May) is most favourable for ocean delivery of particulate nutrients to the reef. The autumn bloom occurs in the core of the Leeuwin Current, where surface chl *a* is relatively uniform throughout the top 70 m, and particulate nutrients sourced from this region are sporadically brought to the reef front via alongshore and cross-shelf transport. It remains to be determined which particular transport mechanisms effect this transport to the reef front, a key variable of interest in determining the reef's response to changes in oceanic conditions.



Node: 3
Title: Ningaloo deepwater habitats and biodiversity

Author: Andrew Heyward
Collaborators: Jamie Colquhoun, Ben Radford, Jane Fromont, Oliver Gomez, Mark Salotti, Shirley Slack Smith, Euan Harvey, Ben Fitzpatrick, Peter Speare, Max Rees, Robert McCauley, Ian Parnum, Miles Parsons, , Emily Twiggs, Sira Tecchiato, Lindsay Collins
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Abstract

The Western Australian jurisdiction of Ningaloo Marine Park (NMP) extends 5.5 km seaward of the reef crest. Although this deeper water region constitutes a majority of the NMP area, with preliminary indications it could support high biodiversity values, it had not been systematically studied at the time the current Management Plan was established. As the zoning of offshore sanctuary zones was based on very limited data and first principles assumptions, the need for additional information was identified as a high priority for future research. This project sought to address this knowledge gap about the benthic habitats and biological communities in the deeper waters (>20 m) beyond the fringing reef. The sampling effort, which involved collaboration across four primary institutions to address the principle objectives, was spread over three years.

The objectives were to:

- Produce an improved bathymetry of the offshore waters of the Ningaloo Marine Park
- Develop a broad scale characterisation of the major benthic habitat types
- Establish a baseline biodiversity inventory of the macro-epibenthos through the collection, preservation and identification of dominant components of the major habitat types
- Provide support for WAMSI Project 3.1.4, to characterise the surficial sediments and seabed geomorphology of the deeper waters of the NMP.

The study focussed on benthic habitats in depths from 20m out to 110 m, or offshore to the NMP State boundary, along the entire length of the Park. A towed video system delivered live video to the ship for classification of seabed substrata and the dominant components of the macro-epibenthos. Biodiversity inventories of the macrobenthos were collected using benthic sleds, while surveys of demersal fish associated with the major habitats were conducted using stereo baited video. Improved bathymetry data was collected using a Simrad single beam depth sounder, deployed progressively at 500m spacing in 2006,2007 and 2008 to cover the majority of the NMP.

The study revealed that the most of the offshore NMP seabed is covered in various forms of sand, but smaller areas of rubble, outcropping ledges and low relief reef are widespread and support diverse and abundant macrobenthos, dominated by sponges. The species assemblages vary with depth and latitude, suggesting that a more spatially equitable distribution of offshore sanctuary or benthic habitat protection zones along the length of the NMP may deliver a zoning strategy closer to CAR principles.

Node: 3

Title: Ningaloo Marine Park: Coral Reef and Coastal Zone Maps achieved with Hyperspectral, Remotely-Sensed Data

Author: Halina Kobryn
Collaborators: Kristin Wouters1, Lynnath E. Beckley and Thomas Heege
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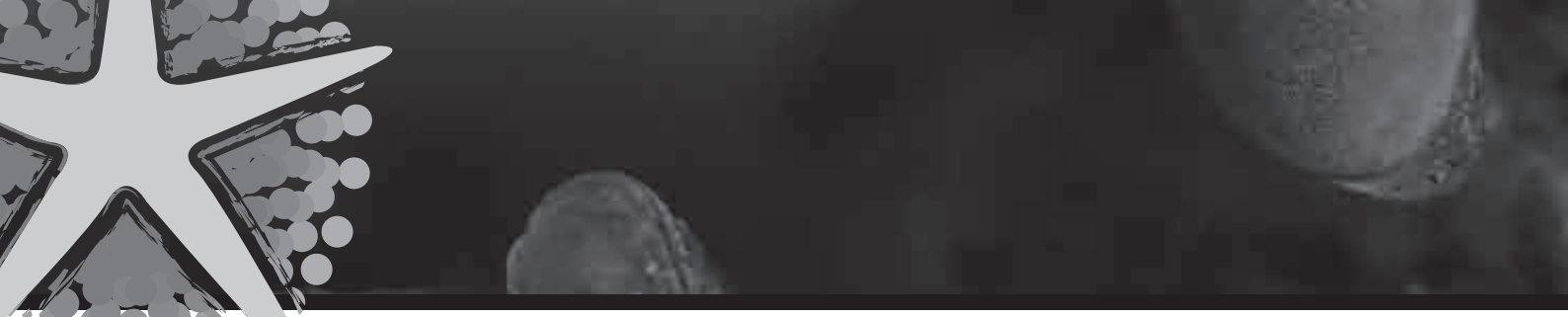
Abstract

Effective management and monitoring of large marine protected areas requires detailed baseline data about the distribution of marine habitats. Large areas with complex geomorphology and clear waters, such as Ningaloo Marine Park (NMP) in Western Australia, naturally lend themselves to the application of optical remote sensing (hyperspectral data) as a means of gathering information about benthic habitats, bathymetry and adjacent coastal environments.

By analysis of HyVista hyperspectral data (3.5m pixels with 0.4-2.5 Um spectral range), we were able to retrieve very detailed information about Ningaloo Reef (down to 20m depth). Data products include hierarchical thematic classification with up to 46 benthic cover classes as well as per-class probability and objected-oriented classification which combined benthic classes, depth, slope and aspect. From these we established that:

- over 50% of the substrate cover is composed of macro- or turfing algae;
- hard and soft coral cover makes up only 7% of the study area;
- 52% (875ha) of the coral cover is located within the sanctuary zones;
- the majority of the corals are a mix of different densities or morphologies of Acropora;
- within pixels, the majority of the hard coral cover occurs as either very dense cover (>90%) or with a patchy distribution (20-45%).

Examination of the adjacent coastal areas showed that vegetation cover was highly variable with evidence of anthropogenic influence through 4WD tracks, erosion and weed invasion. Pastoral leases had the highest track densities (8.1 km per km 2) whereas, in contrast, Cape Range National Park had the lowest track density (0.3 km per km 2). Through the use of operational pre -processing of the data and a semi-automatic image classification approach we created seamless high resolution baseline maps for 3400km 2 of the Ningaloo region which are particularly suitable for ongoing monitoring and management.



Node: 3
Title: Effectiveness of Sanctuary Zones - Overview

Author: Russ Babcock
Collaborators: Mat Vanderklift, Mick Haywood, Rich Pillans, Doug Bearham, Fiona Graham, Geordie Clapin
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Abstract

This project took a broad range of approaches to assess multiple aspects of coral reef ecosystems at Ningaloo relevant to current and future management of the Ningaloo Marine Park and Muiron Islands Marine Management Area. The assessment of the zoning of the marine park has in general confirmed that the zoning implemented in 1991 has achieved positive outcomes in terms of biodiversity protection and that the recent rezoning is likely to achieve further conservation outcomes as intended. It also highlights the need for ongoing evaluation of marine park effectiveness in relation to both zoning and overall management as there are indications from a range of sources that there may be aspects of park configuration requiring further management action in order to realise park management goals.

Assessments of fish populations across a range of previously established sanctuary zones revealed higher biomass of targeted species spangled emperor *(Lethrinus nebulosus*), yellowtailed emperor (*Lethrinus atkinsoni*) and cod (*Epinephelus rivulatus*) across multiple sanctuary zones. Other species showed significant increases in specific sanctuary zones, a pattern that depended on regional variation in the distribution of some species (e.g. mangrove jack *Lutjanus argentimaculatus* at Bundegi). The size of these effects was relatively small, generally less than a doubling in biomass. Importantly, surveys also revealed that for some taxa the differences between sanctuary zones and fished areas were smaller than variations in targeted species biomass related to gradients in fishing pressure, with sharks, trevallies, groupers and emperors showing significantly higher biomass in areas with low fishing pressure. Limited historical data suggests densities of spangled emperor and western rock lobster are lower now than in the 1980s.

There were few indications that indirect effects of fishing are having a substantial impact on food webs at Ningaloo. While some small predatory fish species (e.g. wrasses) were less abundant inside no-take zones, possibly due to competition or predation by protected target species, these effects did not extend to other trophic groups and most herbivorous fish, invertebrates (urchins and *Drupella*), corals and macroalgae showed no consistent trends between no-take sanctuary zones and recreationally fished areas. Parrotfish were found by several independent surveys to be more abundant in no-take zones. The mechanisms responsible for this pattern are not clear, but it is important to understand them if this finding is to be fully used to inform management practices aimed at promoting the resilience of coral reef ecosystems. Comparisons of the biomass of grazing fish and macroalgae we have shown that 100 $kg.ha^{-1}$ grazing may be required to maintain low macroalgal biomass on these reefs.

Tracking of fish using acoustic tagging at Ningaloo have provided information on the habitat types and area of reef characteristically used by key species, as well as the timing of important behaviours such as spawning. For example spangled emperors make far more use of nearshore habitats than was previously appreciated, a behaviour that might render them more susceptible to beach fishing. They also show regular spawning migrations to unknown off-reef areas in October-December. Such information may be used in reviewing the existing zoning or in the zoning of other parks in northwest Australia. Planning for future sanctuary zones could incorporate these measurements into modelling approaches to provide a basis for determining optimal size of sanctuary zones.

Node: 3
Title: Node 3. Fish biodiversity and assemblages

Author: Euan Harvey
Collaborators: Ben Fitzpatrick, Mike Cappo, Stephen Newman, Ben Radford, Andrew Heyward, Russ Babcock
Institution: The University of Western Australia
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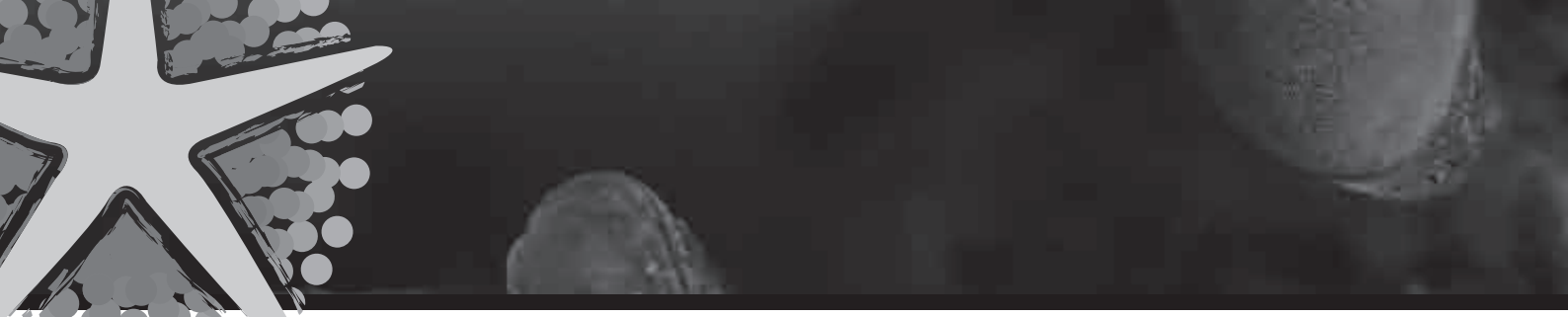
Abstract

We investigated differences in the distributions and length of key fishes, fish assemblages and fish biodiversity occupying the inshore and offshore benthic habitats of the Ningaloo reef and adjacent continental shelf. In particular we were interested in whether there were differences between the inshore and offshore benthic habitats and between the northern (Tantabiddi), central (Point Cloates) and southern (Gnarloo) sections of the Marine Park.

Research undertaken by Ben Fitzpatrick (a WAMSI PhD student) investigated the implications of fine scale habitat associations in coral reef fish assemblages for the design and effectiveness of marine protected areas. This contributes towards a better understanding the effect of human impacts on coral reefs. In the fringing reef environment fish assemblages from nearshore algal reef, deeper backreef channels with *Porites* bommies, branching Acropora patch reefs, tabulate *Acropora*-dominated backreef, rubble-dominated backreef and reef pass habitats were sampled using both diver operated stereo-video (Stereo-DOVs) and Baited remote underwater stereo-video (Stereo BRUVs) inside and outside of two sanctuary zones. There were significant differences in the fish assemblages among habitats and within habitats as well as between Recreation Zones and Sanctuary Zones. This variation was driven by both target and non-target species, many of which had specific habitat affiliations. In general target species and many non-target species were more abundant and/or larger inside sanctuary zones, while some non-target species were larger and/or more abundant in areas open to fishing. In general these differences in the fish assemblages inside and outside sanctuary zones were consistent through four sampling periods.

Seawards of the reef crest, sampling with Stereo BRUVs in benthic habitats from the outer reef (15 m) to the continental shelf slope (350 m) showed there was clear partitioning of fish assemblages between habitat/depth strata. Different size classes of the same species were observed occupying different parts of the shelf and species within a family could be dominant in certain habitats. Higher order predators, including species of Lethrinidae, Carangidae, Serranidae and Lutjanidae were found associated with most habitat types and their abundance and length increased with water depth. There were some differences in the assemblage structure between the northern, middle and southern sections that were sampled. There are distinctive fish assemblages in the deeper waters which have been included in no-take zones for the first time as part of the rezoning in 2006. These assemblages include those associated with the deep mesophotic algae/sand and megabenthos habitats below 47 metres and the subphotic shelf, mid shelf, but not the outer shelf and deep slope habitats which are not represented in the current marine park zoning but also have distinctive fish assemblages.



Node: 3
Title: The Ningaloo Atlas: Sharing knowledge of the Ningaloo region

Author: Tyrone Ridgway
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Email: t.ridgway@aims.gov.au

Abstract

Recent funding by the Western Australian Marine Science Institution (WAMSI) and CSIRO Wealth from Oceans Flagship program have led to a significant boost in research effort in the Ningaloo region – resulting in ~90 scientific publications being published since 2005. At the same time, despite its remote location, recreational use of the Ningaloo region has increased, with 203,580 visitors estimated in 2003, and increases in visitor numbers expected due to the recent World Heritage listing of the Ningaloo Coast. Due to the current and expected growth, there is a need for more comprehensive and accessible information on environmental and socio-economic data for the Ningaloo region. As such, the Ningaloo Atlas has been created as a user-friendly knowledge management system and communication portal with an objective to integrate and share knowledge, foster collaboration, and assist in informed decision making. By using the latest web technologies, the Ningaloo Atlas is intended to be a one-stop shop that provides:

- A web portal to share information online.
- An information repository for the Ningaloo region.
- Free access to information to facilitate research and decision making.
- A bibliographic database of peer-reviewed and non-peer reviewed information.
- A user friendly site to engage a non-scientific audience to explore and learn about the Ningaloo region.

In essence, the Ningaloo Atlas project is a partnership between government organisations, non-government organisations, researchers, industry, and community groups to improve our understanding and raise awareness of the Ningaloo region. The Ningaloo Atlas staff therefore encourages your contribution and are happy to work with you to generate content for the Atlas and showcase your research to a wider audience.

Visit the Ningaloo Atlas and associated blog at http://ningaloo-atlas.org.au or contact us at ningaloo@aims.gov.au.

Node: 3

Title: Growth history, geomorphology and sediments of the Ningaloo Reef and adjacent shelf

Author: Emily Twiggs and Lindsay Collins
Collaborators: Sira Tecchiato (Curtin), Ben Fitzpatrick (UWA), AIMS
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Abstract

The aim of **WAMSI Project 3.4** was to identify evolutionary characteristics of the Ningaloo Reef and shelf relevant to the conservation of marine biodiversity and climate change impacts. A number of research questions were investigated:

3.4.1. What is the morphological history of Ningaloo Reef and surrounding areas and can it provide an insight into reef response to future climate change?

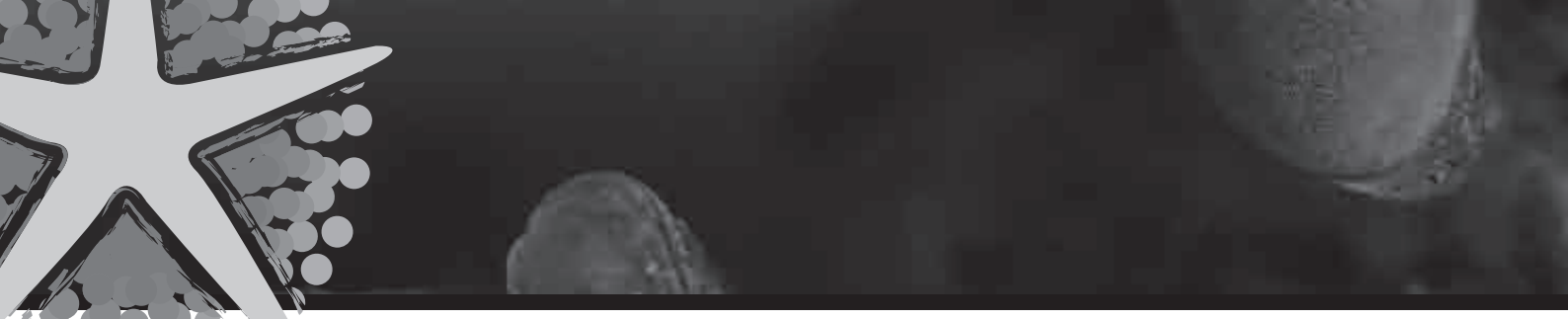
3.4.2. What are the key geomorphic features and sedimentary environments of the reef system and shelf and how do these relate to the distribution of benthic communities?

To approach these questions, coring and U-series dating provided an insight into the Quaternary growth history of both the western and eastern Ningaloo Reef. Investigations using remote sensing, benthic video and sediment grabs were undertaken to map and characterise bathymetry, geomorphology, sedimentary bedforms, surficial sediments and associated communities.

Ancestral reef, alluvial fan and karst topography are the primary physical controls on Holocene reef growth, facies development, geomorphology and contemporary community zonation. The chronological framework developed shows the contrasting pattern of eastern and western reef development. The Ningaloo Reef experienced sea-level fluctuations that were at similar, if not greater magnitudes than those projected with climate change. The study of the eastern Ningaloo Reef demonstrates that a combination of natural processes (fluctuating sea-level, flooding, increased sedimentation and turbidity, alongside severe storm activity) likely contributed to the demise of a section of the reef during the mid-Holocene, providing an analogue for climate change assessments.

Geomorphic features on the shelf represent a complex framework of Pleistocene limestone bedrock mantled with mobile relict and Holocene carbonate sediments that are a proxy for the habitats that produced them. Shelf zonation has been characterised based on bathymetry and distinct geomorphic features (reefs, platforms, ridges, bedforms, sand flats and submarine fans). Reefs, platforms and ridges represent a complex history of reef growth and paleo-shoreline erosion during fluctuating sea-level. Sedimentary bedforms indicate active transport pathways and the interaction of local currents, the Ningaloo and Leeuwin Currents. Exposed hardgrounds and gravelly sediments provide a favourable substrate for diverse mixed communities dominated by encrusting red coralline algae and attaching soft corals, sponges and bryozoans.

Whilst much of the analysis in this project focused on the provision of baseline information, it links closely to the biodiversity projects within Node 3 and provides a basis for additional habitat studies, monitoring and ongoing conservation and management of biodiversity values in the Ningaloo Marine Park.



Node: 3
Title: Oceanographic processes and water circulation

Author: Chari Pattiaratchi
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Abstract

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). This project was designed to examine the role of surface gravity waves, tides and wind on the circulation of Ningaloo using field data and numerical modelling. An extensive field data set was collected over a 6 week field experiment in Sandy Bay and included surface waves, current velocities, tidal level, wind speed and high resolution bathymetry. A high correlation between current velocity and wave heights revealed the significance of waves in driving currents within the lagoon, whilst the modulation of current speed at tidal frequencies in the spectrum suggested the response of circulation to tidal variation over the reef. The influence of various forcing mechanisms on the current field was investigated for both high and low frequency bands. Wave breaking was found to be the dominant forcing mechanism for the low frequency (sub-tidal) currents, with the sub-tidal flow pattern consisting of a cross reef flow over the reef, alongshore flow in the lagoon, and water exiting back to the ocean through the main channel. The tides controlled the high frequency current variability via two mechanisms: one associated with the ebb flood cycle of the tides and the second associated with tidal modulations of the wave driven currents. Wind forcing and buoyancy effects were both found to be negligible in driving the circulation and flushing of the system during the observation period. Flushing time scale estimates varied from as low as 2 h to more than a day for the wide range of observed incident wave heights.

The Regional Ocean Modelling System (ROMS) ocean circulation model was used to simulate the waves, mean currents and mean water levels in Sandy Bay and validated using the field dataset. A detailed momentum budget analysis of the results showed that, on the reef, a dominant cross-shore balance exists between the radiation stress gradients and a pressure (mean water level) gradient (similar to a beach), and alongshore currents within the lagoon were driven by alongshore differences in wave setup which drove flow towards the channels. To investigate the importance of these wave driven currents over an annual cycle, the model was extended with forcing representative of different seasons including both summer, when the winds are on average significantly stronger, and winter when waves are significantly larger. Results from this seasonal analysis indicated that wave forcing (or specifically wave power) still dominated the circulation and flushing of Ningaloo Reef lagoons throughout the year, with winds playing an insignificant role.

Node: 3
Title: Coastal Groundwater and the Linkages to Ningaloo Reef

Author: Alexandra Stevens
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Abstract

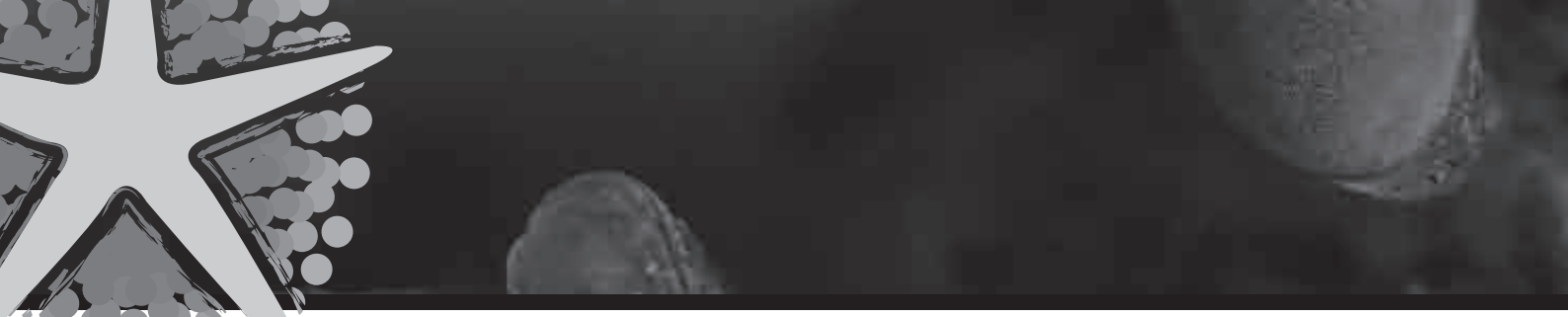
Little is known about the groundwater system and its connectivity with Ningaloo reef but there is sufficient information to indicate that groundwater discharge from the hinterland to the reef system is a significant process which likely has linkages to issues such as stygofauna habitat, water chemistry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

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

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

The second stage of the project involves collaboration with the WA Museum to drill a series of boreholes at Bundera sinkhole and instrument them to examine the stygofauna and monitor groundwater flow and chemistry. This project is still underway and will ultimately describe groundwater dynamics and flow as well as the geological controls and aquifer characteristics of the system. Further, this project is planned to undertake at least one full year of monitoring which will include cyclonic activity. This will give a good indication of how the system works in particular after recharge events. Preliminary data is available and further information will be forthcoming over the next few years.

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



Node: 3
Title: Tagging and tracking the world's largest fish

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Abstract
The past 15 years has seen rapid development of our understanding of the ecology of whale sharks *(Rhincodon typus*) that aggregate seasonally at Ningaloo Reef, WA. Monitoring fine-scale (m-km) movements suggests that whale sharks migrate to Ningaloo to feed on seasonal aggregations of baitfishes and krill, a small shrimp-like animal. Satellite tagging has shown that sharks departing Ningaloo make frequent dives in excess of a kilometre and migrate generally toward the northeast, often into Indonesian waters. Photo-identification (based on spot and stripe patterns) has confirmed that many sharks return to Ningaloo, with some individuals resighted at intervals of more than a decade and a large number of individuals making frequent inter-annual visits. Most sharks in the Ningaloo aggregation have been juvenile males, raising the question: where are the females and adults? I describe threats to whale sharks and our efforts to protect the species into the future.

Node: 3
Project: Trophic effects herbivory at Ningaloo Reef

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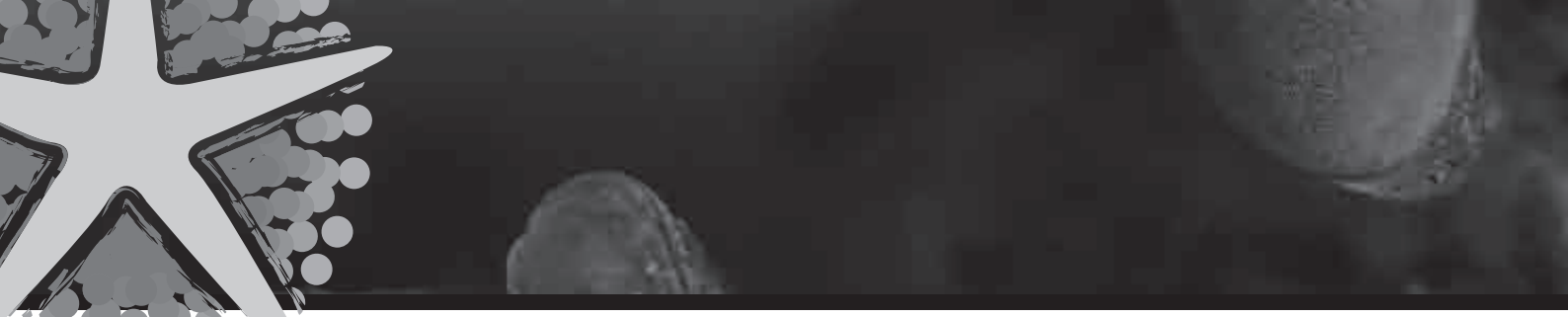
Abstract

Coral reefs are diverse ecosystems which host abundant populations of consumers and algae in spatial mosaics of both coral and algal dominated habitats. A key ecological process in coral-reef ecosystems is herbivory, which has direct effects on macroalgae and indirect effects on corals by influencing the outcome of coral-algal competition. We used a range of approaches to gain an understanding of spatial and species-related patterns in herbivory in five distinct studies. Using underwater video cameras and *Sargassum myriocystum* assays, 23 different fish species were observed consuming macroalgae, but only seven species accounted for 95% of the observed bites across five regions. Of these species, three were identified as the most important in consuming macroalgae: *N. unicornis, Kyphosus* sp. and *K. vaigiensis*. These results were supported by stable isotope analyses that incorporate nutrients from food sources over far longer periods than those examined using the assay approach.

We quantified spatial patterns of macroalgal consumption and food sources across a range of scales. Firstly, across reef habitats separated by hundreds of meters, herbivory was always greatest in the structurally complex coral-dominated outer reef and reef flat habitats, which are also characterised by the highest biomass of herbivorous fish. Secondly, we showed a high degree of variability in grazing rates among regions separated by 100s km in the marine park, with different species responsible for macroalgal removal among those regions. Either *N. unicornis* or *Kyphosus* spp. were responsible for the majority of the grazing. Thirdly, we showed variability in the importance of different food sources across both habitats and regions for some consumers (e.g. *Siganus* spp.) but consistency for other species (e.g. *Naso unicornis, Kyphosus* spp.), which is likely to reflect shifts in food source availability or feeding preferences.

We also characterised the benthic community dynamics of the reef-flat and lagoon habitats to identify seasonal patterns and we experimentally determined the importance of herbivory on algae recruitment in these two habitats. Differences among habitats in algal biomass were strongly influenced by season. Lagoon habitats only had higher biomass than reef-flat habitats during part of the year (late summer/ early autumn). Herbivory had an equally strong effect on the community composition of algal recruits in the lagoon and reef flat habitats, despite the reef flat hosting a herbivorous fish community that was an order of magnitude greater in terms of biomass than the lagoon, which is characterised by younger and smaller fish (e.g. Scarus initial phase).

Management implications will be discussed.



Node: 3
Project: Juvenile fish assemblages of Ningaloo Reef

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Collaborators: Andrew Heyward, Mark Case, Jamie Colquhoun, Rebecca O'Leary, Ben Radford (AIMS): Shaun Wilson, Tom Holmes (DEC)
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Abstract:
The abundance, species richness and assemblage structure of juvenile fishes was quantified in the summers of 2009-2011 along the entire length of Ningaloo. In total, 36,791 juvenile fishes from 120 species were encountered along 691 transects over the three recruitment years, providing an average of 53 individuals $30m^{-2}$. Recruitment rates were far from uniform in time or space. Mean abundance in 2010 was 75% lower than in 2009 or 2011, when recruitment rates were very similar. Peculiarly, this drop in recruitment strength co-incided with an overall increase in mean species diversity and distinct assemblage composition. Spatially, sampling across a number of scales including between locations, reef zones (back reef versus lagoon) and management zones (sanctuary versus recreational) was also highly variable. Locations varied in mean recruitment strength (23 to 111 recruits per transect) with recruitment and species richness means generally highest in the southern section of the Park rather than the eastern or northern sections. Although coral-dominated back reefs generally held higher abundances than macroalgal-dominated lagoons, species richness was similar and both exhibited distinctive assemblages. In fact, many species recruited exclusively to either back reef (16 spp.) or lagoonal habitats (19 spp.). Among these, a number of commercially and/or functionally important groups including the Emperors, Goat and Rabbitfishes recruited solely to lagoon sites revealing the value of these seasonal macroalgal habitats as critical juvenile nurseries. These results clearly demonstrate the importance of censusing all biomes within coral reef ecosystems to ensure species coverage and provide an excellent example of ecological co-evolution and co-dependency on a coral reef.

Node: 3
Project: Current status of the invertebrate fauna targeted by fishers

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Abstract:
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.

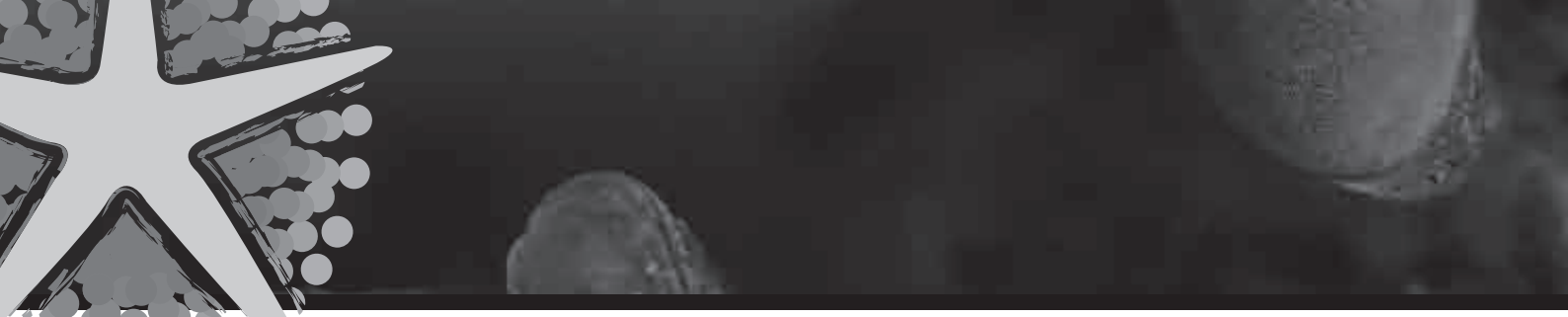
2) Characterising habitats associated with high numbers of these targeted species.

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

Rock lobster The abundance of all 5 species of lobsters were very low (approx 1 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 6-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 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 characterized 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 and Madagascar 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.



Node: 3
Project: Diversity, abundance and distribution of intertidal invertebrates

Author: Anne Brearley
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Email: Anne.Brearley@uwa.edu.au

Abstract

At 36 sites in Ningaloo Marine Park between 2007 and 2010, our quantitative study involving careful searches of replicate 1-m2 quadrats determined the composition of the benthic community of macro-invertebrates on intertidal rocky platforms providing (A) detailed information on variation in biodiversity along the length of the Ningaloo Marine Park, and (B) insights for designing sampling to detect differences among places and changes over time.

Of 289 species found in our samples, 127 species were gastropods, and 92 species were represented by single individuals. Additional sampling of intertidal invertebrates will reveal species not detected by this study. This is a natural, expected consequence of the underlying nature of assemblages of invertebrates.

Analyses of 15 abundant species in 2007 and 2009 indicated that spatial variation was pervasive and overwhelmed temporal variation. Spatial variation among geographical regions, among sites within regions, and among quadrats within sites could be very large. Against this background of spatial and temporal variation, desired trends for "diversity" and "biomass" to be "constant or positive" are clearly ambitious. Long-term studies spanning 5 to 10 years or more will be required to reveal the dynamics of local populations of long-lived intertidal invertebrates such as *Tricacna maxima* and *Echinometra mathaei*. Managers must distinguish between changes that are major rather than minor, foreseen rather than accidental, and prolonged rather than transient.

As an example of the difficulties in detecting trends, we considered cowries as focal species. *Cypraea cauputserpentis* and *C. moneta* were scarce and variable in abundance. Detecting a twofold difference between inside and outside the Jurabi Sanctuary Zone, even with 4 replicate sites in each condition, would have very low statistical power, or require impossibly large numbers of replicate sites. If continued monitoring programs are implemented, they should be planned carefully, with consideration of Type I and Type II errors, defined effect sizes (alternatives to null hypotheses), and in the light of the (large) size of residual variation that pilot studies such as this project suggest will apply. The appropriate unit of independent replication should be a "site" (as used in this project), and the prognosis from our power analyses is that, even for several fold effect sizes, the number of replicate sites per treatment should be several.

Spatial variability in the composition of the assemblages of invertebrates predominated over temporal variation. The assemblages had different membership according to the region of the Park. Sites in Sanctuary Zones, in Special Purpose Areas, onshore from offshore Sanctuary Zones, and in Recreational Zones showed broad overlap in ordinations of the assemblages, indicating that the sites in Sanctuary Zones represent much of the variation in composition of the macroinvertebrates on rocky platforms. Because of the regional differences in species composition of assemblages of intertidal invertebrates, continued monitoring schemes must include sites along the length of Ningaloo Marine Park. In a test of predictions from power analyses, we used 4 sites inside Jurabi Sanctuary Zone and 4 sites outside to determine the effect of a Sanctuary Zone. The assemblages of invertebrates differed inside and outside of the zone. Simulations suggested that, although the 8 sites were necessary to retain that differentiation, the number of quadrats per site could be reduced.

Node: Ningaloo Collaboration Cluster
Project: WFO Cluster visitor destination model

Author: Tod Jones, David Wood and Elizabeth A. Fulton
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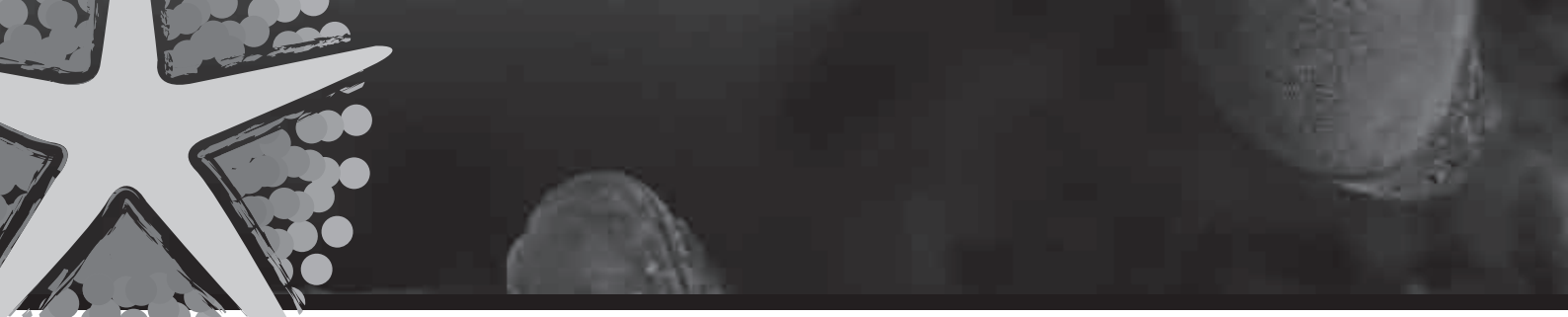
Abstract

The economy of the Ningaloo coastal region, and in particular Exmouth and Coral Bay, relies on nature based tourism. Land use conflicts are frequent, and the region has seen hotly debated disputes over resort developments, marine sanctuaries, and World Heritage nomination. This project addresses land use planning issues by capturing the complexity of the tourism system using the Ningaloo Destination Model (NDM) and the Ningaloo Ecosim with Ecopath (EwE) model developed by Elizabeth Fulton. The NDM is a planning tool that assesses tourism planning scenarios over a thirty year time frame. It provides a range of economic, environmental and social indicators when assessing a planning scenario, linking locations, activities and impacts that are viewed in silos under typical planning assessments.

While the process for developing the model was important for group learning about tourism to Ningaloo, the focus of this presentation is on using the model to explore the linkages between different types of tourism development and management decisions and the outcomes for the Ningaloo Coast's communities, economy and ecology. After providing an overview of tourism on the Ningaloo Coast and the Ningaloo Destination Model, this paper explores four tourism scenarios: the difference between a caravan park and a hotel development in Exmouth; the implications of tourism growth in Exmouth for Cape Range National Park; nodal development versus resort development; and the predicted effects of another terrorism attack in Bali.



Node: WFO Cluster
Title: Human use of Ningaloo Marine Park

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Co-authors: Claire B. Smallwood, Susan A. Moore and Halina T. Kobryn
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Abstract

Understanding where, when, and how many people use the coast is imperative for conservation of marine biodiversity, management of natural coastal assets and location of appropriate infrastructure. This project has provided a robust benchmark of the extent of human use in the Ningaloo Marine Park throughout 2007. Geo-referenced aerial surveys, four-wheel drive coastal surveys and interviews conducted throughout the year along the entire 300km length of the marine park allowed assessment of patterns in boat-based and coastal recreational activities. The use of Ningaloo Marine Park is markedly seasonal with a clear increase in the number of users, and expansion of their spatial extent to cover most of the park, during the period April to October. In the off-season (November to March), people conducting activities in the park are fewer and largely concentrated in Coral Bay and around North West Cape. A wide range of extractive activities, such as recreational fishing, and non-extractive activities, such as snorkelling, surfing, sailing sports, relaxing on the beach and walking, are conducted in the park. The demographic characteristics of people engaged in recreation differed significantly between various areas of the park and were related to road/track access, accommodation opportunities and tenure of the land adjacent to the park. Travel network analysis on how coastal roads, tracks and boat launching areas are utilised highlighted node-based patterns of use as well as rapid decay in use with distance from access points. The relationship between recreational activity types and park zoning was significant, with the strongest association occurring between snorkelling and sanctuary zones. Unsurprisingly, fishing had a strong negative association with sanctuary zones and was largely undertaken in recreation and special purpose (SBA) zones. Nevertheless, non-compliance with sanctuary zones by fishing vessels was 12%, but could be as high as 20% if vessels for which an activity type could not be ascertained were assumed to be fishing. The results of this study provide a solid basis for enhanced management, readily measurable indicators for monitoring of use and are well-suited to systematic conservation planning for the next iteration of the Ningaloo Marine Park Management Plan.

Node: 3
Project: An Evaluation of Management Strategies for Line Fishing in the Ningaloo Marine Park

Author: Richard Little
Collaborators: Olivier Thébaud, Fabio Boschetti, A. David McDonald, Ross Marriott, Brent Wise, Rod Lenanton=
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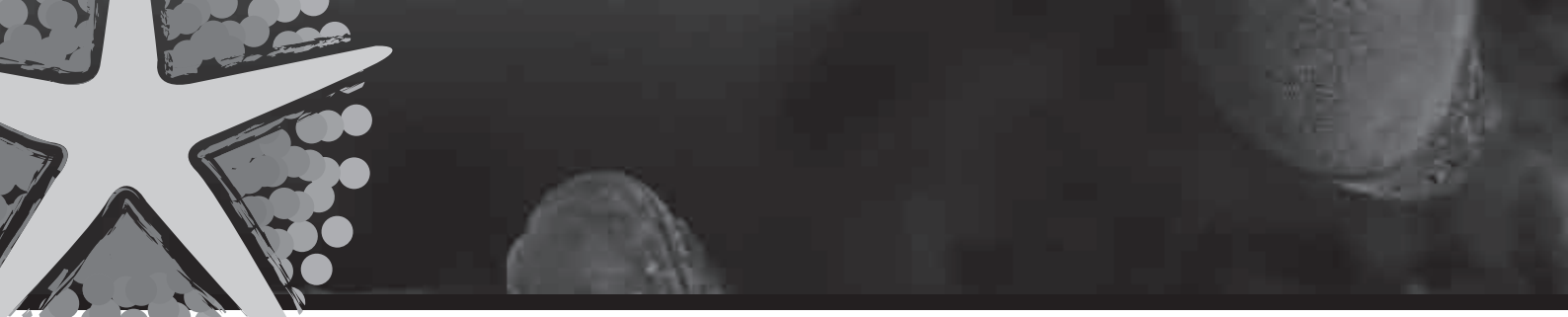
Abstract

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

The simulation model that was used is known as ELFSim (Effect of Line Fishing Simulator). ELFSim is a decision support software system designed to evaluate options for conservation and harvest management, and includes a number of key components: a population dynamics model of the target species that captures the full life history (including larval dispersal, reproduction, development, and habits) of that species, a model of fishing dynamics that captures the exploitation pattern due to fishing behaviour, and a management model that simulates the implementation of management actions.

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

The power of management strategy evaluation is that it can capture and simulate the full actions that are made by management. This could help determine the efficacy of fisheries management procedures that include assessment models estimating the state of the population, and the decision-making process. This offers management a powerful tool to be able to test their management practice(s) in the simulation setting before they implement them in reality.



Node: WFO Cluster
Project: Management strategy evaluation

Author: Beth Fulton
Presenter: Fabio Boschetti
Institution: CSIRO
Email: Beth.Fulton@csiro.au

Abstract

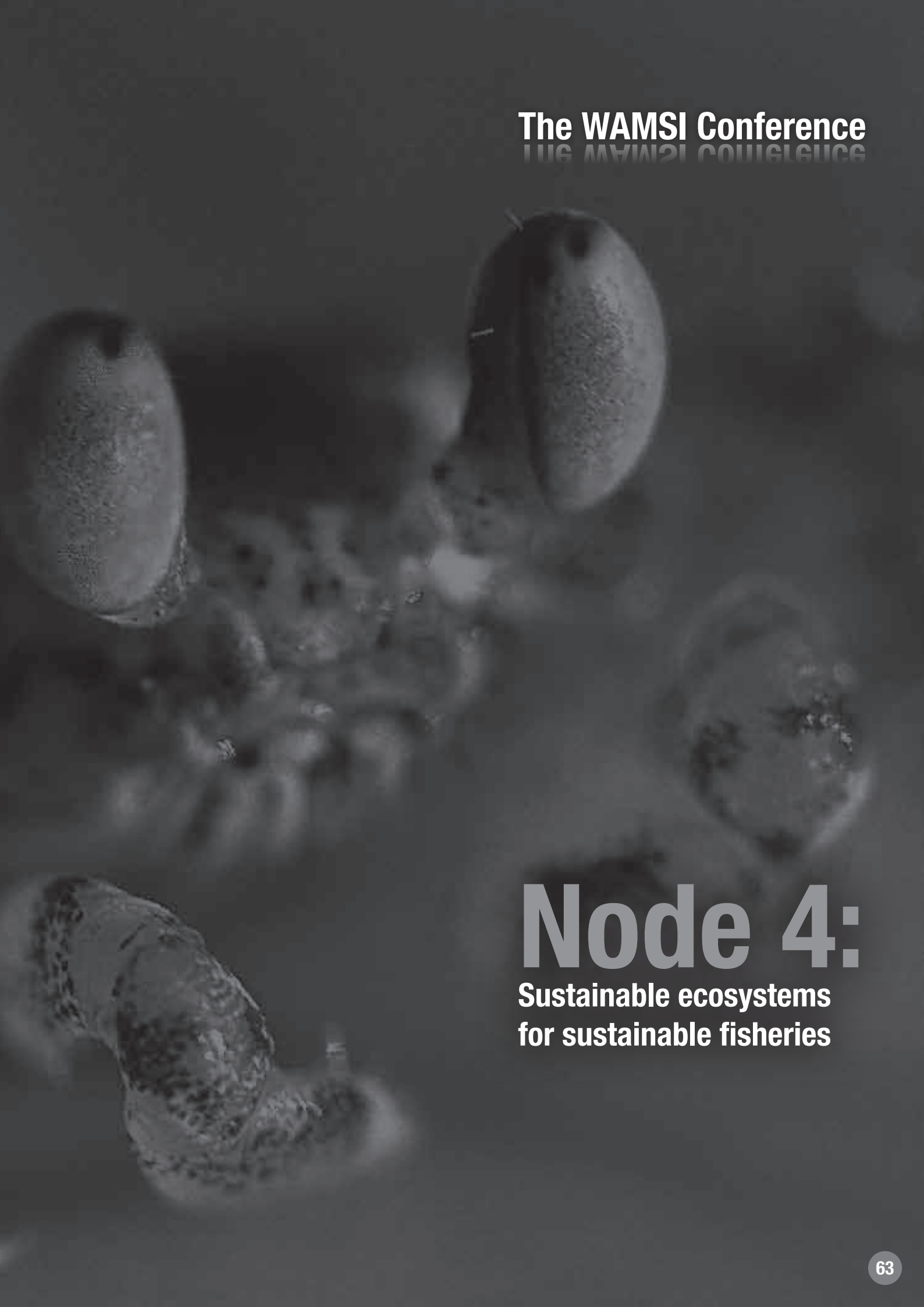
A system-level perspective of exploited marine and coastal ecosystems provides insight into cross-scale dynamics and potential conflicts between sectors operating within the same region. Agent-based models provide one means of obtaining this insight since they can simultaneously account for a large number of scales and processes.

Our modelling approach was implemented within a Management Strategy Evaluation (MSE) framework, which simulates the different steps in adaptive management; specific resource dynamics, actions of those exploiting the resource and associated monitoring initiatives. This allows for an assessment of the performance of available management strategies as well as the identification of tradeoffs between management objectives, within the inevitable uncertainties inherent in any complex socio-ecological-economic system.

After drawing together data from historical sources as well as the recent WAMSI and Ningaloo collaboration cluster projects, a wide range of management strategies and contextual scenarios were defined during extensive interaction with groups interested in the Ningaloo-Exmouth region, specifically addressing the key questions concerning the effects of a range of proposed development initiatives. The results of the model simulations highlight the complex relationships between development and environmental status in the region. They clearly show that any further growth in fishing pressure leads to significant declines in fish stocks. Additional recreational pressure applied by oil and gas workers may be sufficient to cause a collapse in some key species. The simulations also indicate that without some form of socio-economic development there is a significant risk of population decline. The interaction between population size and fishing pressure highlights a direct conflict between economic and conservation objectives. Sustainable futures are possible, but they likely require significant changes to existing regulations.

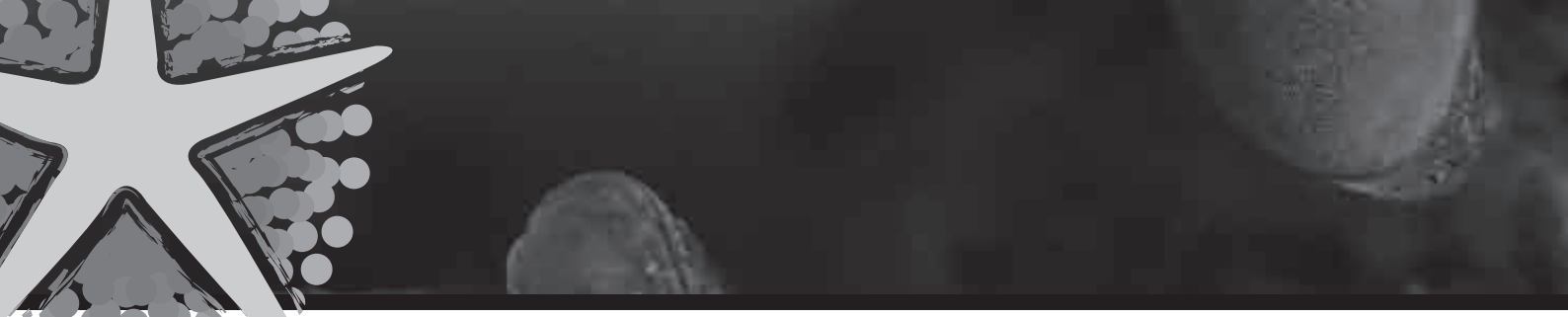
The modelling effort has provided a system-wide understanding of how the Ningaloo region functions. Its usefulness depends on whether the results and recommendations are taken up by stakeholders, which in turn depends on how well this system understanding has reached the community. By the end of the project the modelling team has invested roughly 43% of its overall effort in stakeholder engagement in the form of one-to-one meetings, workshops, seminars and public presentations, aimed at collecting as well as disseminating information. An invaluable learning arose from such process, including how to (i) successfully communicate complex information to people with varying degrees of scientific background, and (ii) support these communities while they address these complex highly interconnected systems.

Very diverse futures are possible for the Ningaloo-Exmouth region over the next 30 years. Fortunately, it appears management interventions are available to steer (at least some components) towards desired directions. Fishing regulations, housing plans, marketing and catering for specific tourist type and infrastructure development are likely to provide the largest impact. This information should help guide decision makers and the local community as they address their specific concerns.



Node 4:

Sustainable ecosystems for sustainable fisheries



Node: 4
Project: Overview of Node 4

Author: Dr Rick Fletcher
Institution: Department of Fisheries WA
Email: rick.fletcher@fish.wa.gov.au

Abstract

Node 4 has developed a world class, risk based framework for the regional management of marine resources. This framework has been adopted by the Department of Fisheries to fully implement EBFM at a bioregional level. This framework has improved priority setting and budget allocation process in the Department to make better and more efficient use of government resources. The system was also being adopted nationally through the Natural Resources Standing Committee to enable implementation of EBM.

This presentation will provide an overview of how this node of WAMSI 1 was a valuable investment by government that has assisted in delivering a major advance in how marine and estuarine ecosystems should be managed. It has highlighted the need for an integrated and holistic approach to the management of coastal ecosystems that must recognise that people are an intrinsic part of the 'ecosystem' and therefore the assessment and management processes.

The lessons learned include that the linkages of other major initiatives (.e.g. IMOS) and new technologies into management systems and processes must become more strategic with the outputs more accessible. There is a need to develop an integrated plan across agencies to improve the outcomes that can be generated for government. Given the cost effective outputs from WAMSI 1, there should be increased involvement of social and economic research within future multi-disciplinary programs.

Node: 4
Project: 1 Applying the EBFM framework

Author: Dr Dan Gaughan
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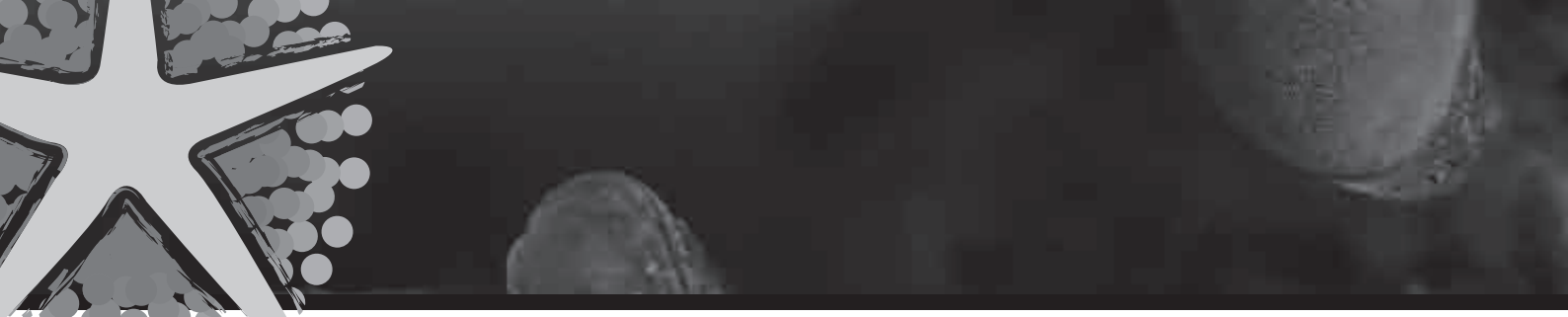
Abstract

This project focussed on developing a better system for holistic management of marine ecosystem and developing a clearer understanding of how both management systems and the ecosystems to be managed are structured.

Risk-based frameworks to implement an 'ecosystem approach' have been developed in Australia for a number of different industries, including for individual fisheries. Whilst valuable, fishery level approaches do not address cumulative effects of fishing or align with regional level planning undertaken by other agencies, nor have they halted increasingly negative community perceptions about fishing. To address these issues, a regional level approach, termed Ecosystem Based Fisheries Management (EBFM), has been trialled.

To avoid merely generating impossibly complex sets of regional issues, uncertainties and expectations, a hierarchical, risk-based framework was developed. In applying the EBFM framework to the West Coast bioregion of Western Australia, stakeholder workshops identified over 600 ecological assets, social and economic issues, governance issues and external drivers. This complexity was reduced by consolidating these into 60 regional-level risks, with a multi-criteria analysis used to integrate related ecological, social and economic values and risks into 24 'Agency level' priorities ranging from urgent to very low priorities. This framework has been applied to all six bioregions in WA with these priorities now used as the basis for annual budget setting. To fully implement EBFM, WA is revising it's legislation and governance arrangement to facilitate creation of regional level strategies to coordinate the management of all individual fisheries/activities and simplify the Department's engagement in future multi-sector (EBM), regional planning processes.

The second part of this project investigated structures of a variety of systems (e.g. estuary ecosystems including governance, behaviour of recreational fishers, rock lobster fishery trophic paths) using qualitative modelling. This highly intuitive, expert–based modelling developed much better understanding of several systems for which data were limited and for which indirect interactions between system components had hitherto not been anticipated or understood. This series of modelling exercises have ongoing benefits to management and sampling design across a variety of areas.



Node: 4
Title: Trophic interactions and ecosystem modelling for Ecosystem Based Fisheries Management

Author: Neil Loneragan
Collaborators: Matt Pember, Linda Bellchambers, Glenn Hyndes, Gary Kendrick, Pippa Moore, Ian Potter, Norm Hall, Sarah Metcalf, Jeffrey Dambacher, Hector Lozano-Montes
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Abstract

This research focussed on two broad areas 1) examining trophic interactions to investigate the ecosystem effects of fishing and 2) investigating the potential for models to understand ecosystem function in our estuarine systems, which are facing increasing pressures of anthropogenic change, such as eutrophication, reduced freshwater flows and algal blooms. The trophic interactions of lobster were examined in the deep waters of Jurien Bay (Department of Fisheries and University of Western Australia), and in the shallow waters of the Perth metropolitan region (Edith Cowan University). In addition to this, PhD research (Murdoch University) determined the feeding of two important species (Silver Trevally and Pink Snapper) and used these data, and those from previous studies, to develop a food web for the demersal fish in the Perth waters. The deep water lobster research was successful in gaining additional funding from the FRDC, and in negotiating the establishment of a scientific closed area with the lobster fishing industry. The deep water benthic habitats of this area have been mapped in detail, and data collected on the abundance and size distribution of lobster in the closed area. These data are being compared with long-term data in a nearby fished area. Qualitative models were used to identify potential species as indicators of ecosystem change and cost-effective methods for monitoring deepwater ecosystems have been developed. Research in the shallow waters found that the abundance of lobster in the sanctuary zones of shallow waters was greater than in open areas, identified the main dietary items of lobster and examined the impact of lobster on the benthos. At the current levels of lobster density, it was difficult to detect a major change in prey or floral abundance in the shallow waters.

The modelling component of the research used workshops to facilitate the development of qualitative models for the Peel-Harvey estuary and determine the types of quantitative models that would be of greatest value to researchers and managers of this system and other estuaries in south-western Australia. In addition to these modelling studies, PhD research developed quantitative models (Ecopath with Ecosim) for the Peel-Harvey Estuary, before and after the opening of the Dawesville Channel. The qualitative and quantitative modelling studies identified the importance of the management and reporting arrangements, with feedback loops to the community, for maintaining and improving the ecosystem health of our estuaries and their catchments. They also highlighted the value of qualitative models for enhancing our understanding of ecosystem function and the potential effectiveness of management arrangements for these complex aquatic ecosystems. In addition, the qualitative models can be used to help develop the structure of the quantitative models by identifying potential functional groups, species and processes that are likely to be important in these models. The workshops and discussions on potential frameworks and development pathways for quantitative models identified several different components of the modelling framework, a pathway for model development and that the model development and results need to be communicated with a range of stakeholders, including the community.

Node: 4
Title: Captured Species Assessments

Author: Dr Brett Molony
Collaborators: Dr Brett Molony, Dr Richard Evans, Dr Gary Jackson, Dr David Fairclough, Dr Rod Lenanton, Dr Phillip England, Dr Oliver Berry, Dr Jenny Chaplin, Ms Michelle Gardner, Dr Daniel Gaughan, Dr Rich Little, Dr Brent Wise
Institution: Department of Fisheries, Western Australia
Email: Brett.Molony@fish.wa.gov.au

Abstract

This collaborative WAMSI project focused on providing advice directly to fisheries managers on three key aspects of wild capture fisheries, primarily located in the West Coast Bioregion of Western Australia;

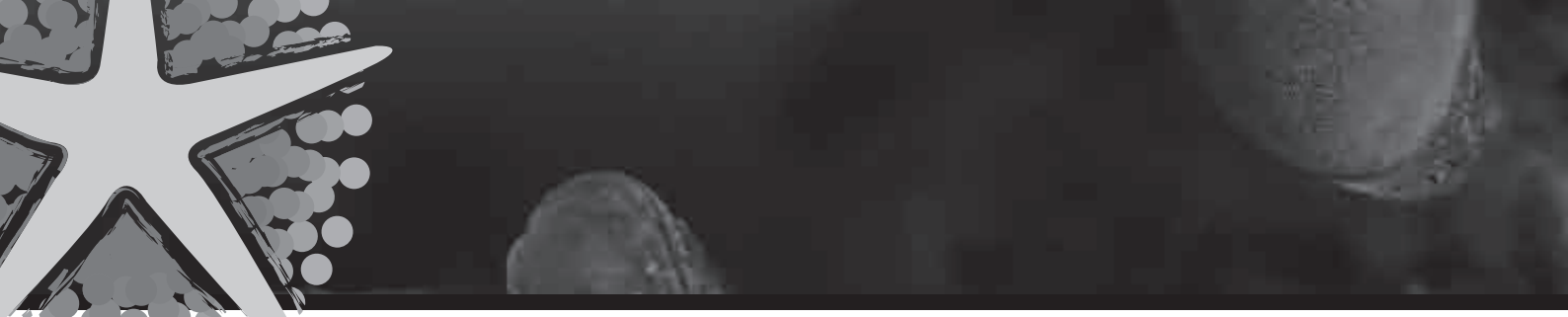
- 4.4.1: Assessment and monitoring methods for bycatch species composition and abundance (Department of Fisheries WA, DoF);
- 4.4.2: Implications of mobility and stock structure of species for management approaches (DoF, CSIRO, Murdoch University)
- 4.4.3: Development of cost-effective methods for monitoring the catch of the non-commercial sector (DoF)

Assessment and monitoring of bycatch represented the first attempt at considering the cumulative bycatch of all extractive fisheries in the West Coast, Gascoyne and South Coast Bioregions. Using a risk-based approach, this sub-project identified that the cumulative effects of extractive fisheries on most bycatch species were low to moderate. Additionally, while data gaps and non-contemporary data were identified for some fisheries, recent management changes would likely have resulted in further reductions in risks to sustainability of byctach species. A pilot trial of boat-based remote cameras was also undertaken, to examine the efficacy of this technique to enhance data collection.

Stock structure and connectivity of indicator species for the West Coast demersal scalefish resource – West Australian dhufish, pink snapper and baldchin groper – were assessed against management boundaries using otolith chemistry (stable isotope and trace elements) and genetic techniques. A single genetic stock of both dhufish and baldchin exists along the West Coast. However, otolith microchemistry data indicate that individuals of both species appear to settle to the areas where they will remain as adults. Preliminary results suggest that pink snapper also comprises a contiguous genetic stock, extending as far north as oceanic waters outside Shark Bay and to the South Coast. Microchemistry indicates that adult snapper do not typically move long distances, however those at any one location originate from a range of nurseries. The stock structure is being compared to management boundaries to determine if the spatial management is robust enough to reduce the risks of localised depletion. Modelling of dhufish (via ELFSIM) is currently underway to formally evaluate the management regime for the West Coast Demersal Scalefish Resource under a range of scenarios.

The recreational fishery sector is rapidly expanding and estimates of catch and effort are essential for monitoring this sector. A WAMSI funded international workshop reviewed the approaches used by the Department of Fisheries and proposed survey methods to generate robust estimates of catch and effort based on the new recreational fishing from boat license. The unique challenges in Western Australia including remote areas, ‘fly-in-fly-out’ workers and ‘grey nomads’ necessitated the implementation of an integrated survey based on complementary survey methods and will result in estimates of State-wide catch and effort from the boat based recreational sector being delivered in 2012.

The approaches, methods and hardware developed in 4.4 are also being applied to other fish stocks and fisheries by DoFWA, including further collaborative projects which will extend outcomes of the WAMSI investment.



Node: 4
Project: Modelling Recreational Fishing behaviour

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Collaborators: Seamus McElroy
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Abstract

A model of recreational fisher behaviour is developed in which fishers optimize fishing time per trip and the number of trips per year conditional on fishing opportunities, constraints on fishing and the opportunity cost of their rime. It shows that as binding constraints are implied (e.g. tighter bag limits) fishers behaving rationally will shorten trip time, shorten fishing time and will shift a portion of trip time to other non fishing activities.

A 2003 survey of individual fishers from the West Coast Demersal fishery was used as the benchmark for the unconstrained fishing case. In 2010 bag limits were tightened substantially and recreational fishing licenses, including boat licenses were introduced along with a closed season, ending on Dec 15 2009. A 2010 survey was undertaken in April/May to 2010 to collect data on fishing behaviour post the implementation of the new regulations.

Comparison across the surveys illustrates how fisher behaviour changed. The analysis produced several findings. Trips times have reduced significantly. Total trip time, ocean time and time spent fishing for bottom fish and other species has reduced significantly. Non fishing time per trip has increased significantly. All the differences in means for these trip time variables are statistically different between the two surveys.

Consistent with the intent of the new rules, catch per trip is significantly less for the prized and high risk demersal scale fish. Satisfaction scores for catch, species caught, time to catch fish and size are all significantly lower in the 2010 survey. However, satisfaction with the overall fishing experience and with time on the ocean is not significantly lower.

Overall, fishers have reduced trip and fish times consistent with the model; catches are lower. The lower satisfaction scores for catch variables reflect this. However, it appears that fishers have been able to adjust their activities while on a fishing trip such that overall satisfaction is not significantly reduced.

Catch rate is found to be significantly connected to trips per annum in both surveys. As expected catch rate increases the number of trips rises but at a decreasing rate. If regulations that reduce effort have the effect of improving catchability and catch rates, then there is expected to be some positive trip response. The analysis indicates that the probability of going bottom fishing weekly and fortnightly as opposed to monthly increases significantly with catch rate.

Node: 4
Project: Socio-Economic Assessment of Scalefish Fisheries (Inshore Demersal) in the West Coast Bioregion

Author: Seamus McElroy and Joseph Christensen
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Institution: University of Western Australia, Murdoch University
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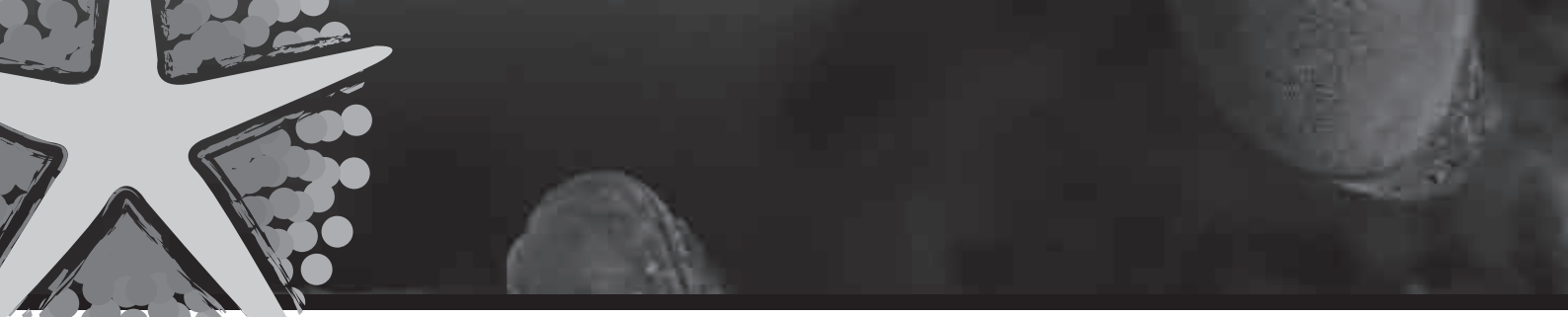
Abstract

Recent major changes to the management of the inshore demersal species suite, West Coast Bioregion, have impacted upon the operation and profitability of the West Coast Demersal Scalefish (WCDS) fishery and the Western Australian Charter Boat industry. For both the WCDS fishery (commercial sector) and the Charter Boat industry (recreational sector), the period 2008 to 2010 witnessed declining catches, a decline in net revenue for each sector, and a fall in the number of active operators in each sector.

This presentation will examine the impact of recent management changes for each of the WCDS fishery and Charter Boat industries. The historical development of each sector will be reviewed, and the financial and socio-economic impacts of management changes over the period 2008-10 are examined. Management implications arising from adaptive strategies of active operators in each of these sectors are also considered.

The presentation draws upon the results of a financial and socio-economic survey of the WCDS fishery and Charter Boat industry, and an analysis of catch and effort data for each sector undertaken with the support of the Department of Fisheries Western Australia.



Node: 4

Title: An overview of Node 4.2: Assessment of Marine Communities and the Impact of Anthropogenic Influences

Author: Euan Harvey
Collaborators: Norm Hall, Ian Potter, Peter Coulson, Steeg Hoeksema, Lauren Veale, Chris Hallett, Fiona Valesini, Tim Langlois, Daniel Smale, Gary Kendrick, Kimberly Van Niel, Jessica Meeuwig, Nic Caputi, Alan Pearce
Institution: The University of Western Australia
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Abstract

In this presentation I provide an introduction to and overview of Node 4.2: Assessment of Marine Communities and the Impact of Anthropogenic Influences. This node had four major projects and 2subprojects and involved 15 staff and students from Murdoch, The Department of Fisheries WA and the University of Western Australia.

The projects were based around two core questions:

1. What changes, if any, are occurring in the biodiversity, community structure or habitats within each priority bioregion?
2. Where practical, identify whether fishing or any other factor (eg climate change, pollution) is having an unacceptable level of impact on these elements?

I will introduce the core questions and locations where detailed studies occurred before inviting the 4 of the core researchers to outline their key findings.

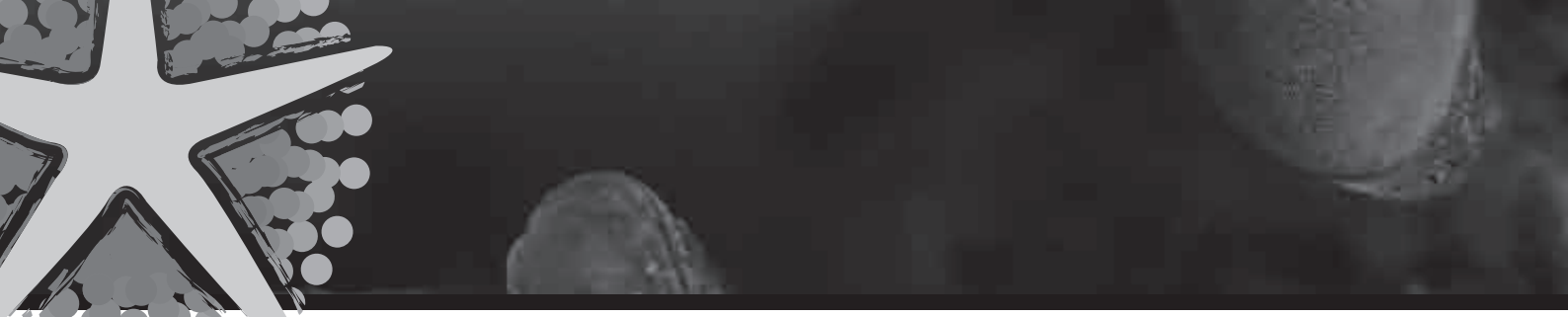
Node: 4
Project: Assessments of the status of community structure based on fishery independent data

Author: Peter Coulson
Collaborators: Ian Potter, Steeg Hoeksema, Lauren Veale
Institution: Murdoch University
Email: p.coulson@murdoch.edu.au

Abstract

This project aimed to determine the possibility of generating cost-effective, fishery-independent monitoring programs for fish communities in areas where commercial fishing supplies insufficient information (e.g. in selected estuaries). Sampling of nearshore ichthyofaunal assemblages throughout the Peel-Harvey Estuary and the Leschenault Inlet was conducted in each of the eight consecutive seasons between winter 2008 and autumn 2010, at the same sites as those sampled in previous studies of these two systems. Data collected using a 102.5 m seine net in the Peel-Harvey Estuary during 2008-10 were compared with the results of fishery-independent studies of this system carried out using the same methodology in 1980-81, when macroalgal growth was close to its maximum and, in 1996-97, two to three years after the opening of the artificial Dawesville Channel. Data from the Leschenault Inlet in 2008-10 were compared with those from a previous study of this system in 1994, a 21.5 m seine net having been used in both periods to ensure comparability. The compositions of the fish fauna of the Peel-Harvey Estuary in the 1990s and particularly 2000s were distinguished from that of the 1980s by consistently far greater numbers of the Weeping Toadfish, *Torquigener pleurogramma.*

Moreover, the greater abundance of the weed-associated species, the Western Gobbleguts, *Apogon rueppelli*, in the Peel-Harvey during the 1980s and 2000s, compared to that in the intervening period, is consistent with the observed decrease in macroalgal biomass which followed the construction of the Dawesville Channel, and anecdotal reports that macroalgal growth subsequently increased between the 1990s and 2000s. While densities of commercial and recreational fish species (*Aldrichetta forsteri, Mugil cephalus, Sillago schomburgkii* and *Sillaginodes punctata*) in the Leschenault Inlet did not show a consistent overall change between 1994 and 2008-10, the ichthyofaunal composition of this system differed conspicuously between the mid-1990s and late-2000s in that two tropical species of Hardyhead (*Craterocephalus mugiloides* and *Atherinomorous vaigensis*) colonised the estuary in the intervening period, when coastal water temperatures rose. The results of this subproject have thus provided valuable data on the current status of the fish fauna in these systems, elucidated the important changes that have occurred in the composition of the fish fauna of these estuaries over the last twenty five years and reinforced the need for the cost-effective, fishery-independent monitoring strategies developed during this project to be applied in an ongoing capacity in these systems and others across the south-west bioregion.



Node: 4
Project: Development and validation of an estuarine health index using fish community characteristics

Author: Chris Hallett
Collaborators: Fiona Valesini, Norm Hall
Institution: Murdoch University
Email: c.hallett@murdoch.edu.au

Abstract

This subproject aimed to develop and evaluate a quantitative, multi-metric, biotic index of estuarine health for the Swan Estuary, and potentially other estuaries in south-western Australia, based on characteristics of its ichthyofauna. This study has succeeded in developing health indices for nearshore and offshore waters of this system, which are the first such tools to be produced for Western Australian estuaries. A suite of fish community characteristics (metrics), including measures of species composition, diversity and abundance, trophic structure and life history function, were selected via a novel weight of evidence approach, on the basis of their sensitivity to detect inter-annual change in estuarine condition. Seasonally-adjusted reference conditions for each selected metric were established for each region of the Swan Estuary using 30 years' of historical fish assemblage data, and thus represent a best available standard of biotic integrity against which the current and future health of the estuary may be assessed and compared. Scores for each metric were assigned according to the extent of the metric's deviation from its reference condition, and values for the health indices were then calculated from summed metric scores.

The resulting quantitative index scores, and corresponding qualitative health status classifications (good, fair, poor, very poor), may then be used to compare ecosystem health across estuarine zones, seasons and years. Examination of the changes in mean nearshore health index scores between 1976 and 2009 suggests that the health of the nearshore waters of the Swan Estuary has remained relatively constant over the last three decades. In contrast, the mean offshore health index score has decreased consistently from 56.5 in the late 1970s to 47 in 2008/09, resulting in the health status of the offshore waters of the estuary being classified as poor during the most recent study period, for the first time in three decades. The consistent decrease observed in offshore health index scores over the last three decades suggests that the index developed during this project is capable of detecting the widely-perceived, long-term decline in the condition of offshore waters of the Swan Estuary. Moreover, the findings from a current study, which has continued the work of this subproject, suggest that the nearshore index is sensitive to small-scale, short-term environmental perturbations such as algal blooms. Overall, validation of the indices developed during this study demonstrated that classification of the health status of the estuary was fairly robust, despite the effects of both natural spatio-temporal variability and sampling error on index scores. These indices thus deliver a reliable, practical and cost-effective method for quantifying the status of estuarine health, providing managers with a sound basis for preventative management actions and a means for communicating ecosystem health implications to the wider public.

Node: 4
Project: Assessment of marine communities and the impact of anthropogenic influences

Author: Tim Langlois, Daniel Smale, Gary Kendrick, Kimberly Van Niel, Jessica Meeuwig, Euan Harvey
Collaborators: Tim Langlois, Daniel Smale, Gary Kendrick, Kimberly Van Niel, Jessica Meeuwig, Euan Harvey
Institution: The University of Western Australia
Email: timothy.langlois@uwa.edu.au

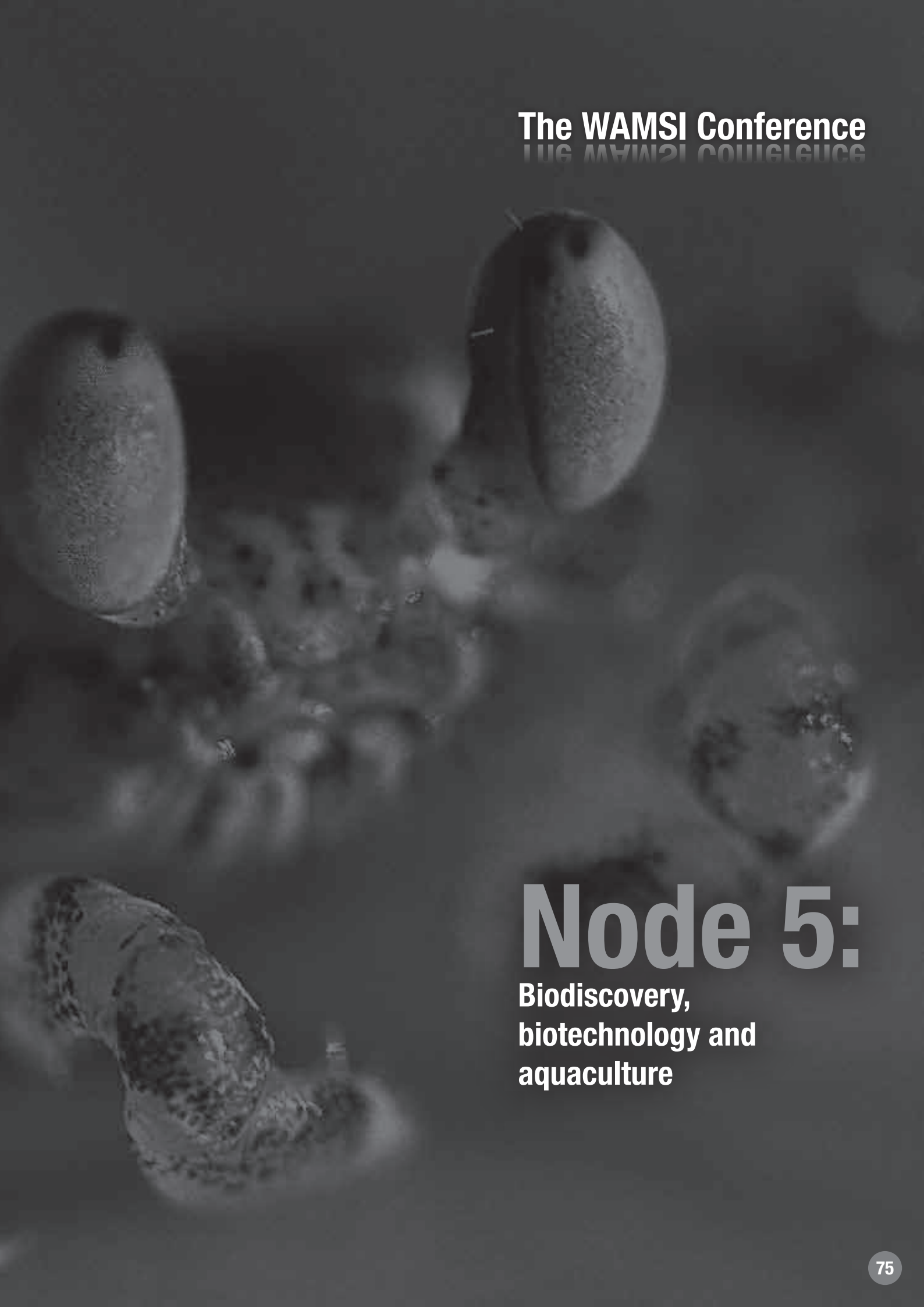
Abstract
The establishment of long term monitoring program (LTMP) is essential to investigate how and why marine communities change through time. This project focused on the selection of representative metrics of the fish and benthic community, which can be used to track any changes, and the cost-effective design and methods for monitoring programs.

There were five main objectives:

- Determination of indicator regions and selection of potential indicators
- Development of monitoring strategies and cost-effective methods
- Implementation of sampling program for LTMP
- Assessment of effectiveness of LTMP and recommendations for expansion into other areas
- In particular, this project provided input to WAMSI Node 4.1 " Applying the EBFM framework" and received valuable help with oceanographic information from WAMSI Node 2 "Climate Processes, Predictability and Impacts in a Warming Ocean".

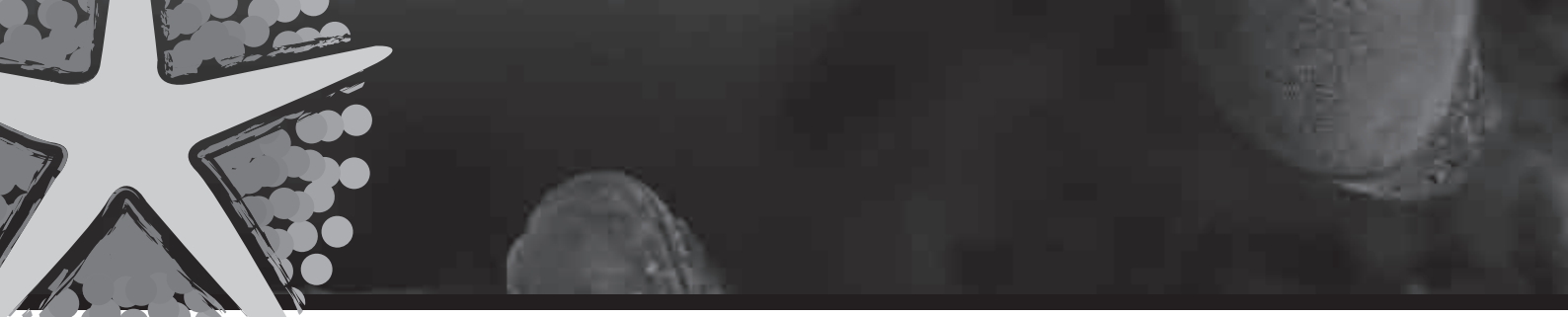
The LTMP for fish assemblages has combined existing baseline and other time-series data to construct a regional multi-species model. Initial results suggest this regional model will be sensitive to detecting subtle trends in the fish assemblage associated with trends in the temperate or tropical dominance of the fish assemblage. This regional multi-species model will provide a reliable indicator of temperature related changes in the fish assemblage.

The development of the LTMP for benthic assemblages has focussed on the application of Autonomous Underwater Vehicle (AUV) technology for sustained ecological observations. Extensive AUV surveys have been conducted at 3 key locations in successive years, in conjunction with an IMOS-funded national programme. Preliminary analyses have demonstrated the cost-effectiveness of the methodology and high statistical power to detect change. Benthic assemblages at 18 reference sites have been 'benchmarked' to facilitate an ongoing examination of temporal variability in habitat quality and extent, and seabed biodiversity.



Node 5:

Biodiscovery, biotechnology and aquaculture



Node: 5
Project: Marine biodiscovery, biotechnology and aquaculture: the blue farm

Author: Howard Shawcross
Collaborators: Jane Fromont, Peter Leedman, David Sutton and Jamie Summerfield
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Email: Howard.shawcross@commerce.wa.gov.au

Abstract

Marine Biodiscovery and Biotechnology within WAMSI is designed to capitalise on the uniqueness and profusion of the States marine biodiversity and to assist the development of a marine component to Western Australia's emerging biotechnology industry. The growth of the Western Australian Institute of Medical Research (WAIMR), Western Australian Chemistry Centre and an unprecedented focus on the marine estate both for conservation purposes and in response to development of the oil and gas industry, provides an unequalled opportunity for exploration of marine biodiversity in Western Australia and examination of applications across all sectors. The main hurdle limiting progress in the marine biotechnology sector in Western Australia has been a lack of a legislative framework to underpin security for biodiscovery investment. Node 5 is organised into three projects focusing on (1) a marine bioresources repository, (2) bioactive compounds extracted from marine samples and (3) the identification and purification of quorum quenching compounds from marine invertebrates and bacteria. This Node provides a strategic case study outlining the value of the initial WAMSI investment that has facilitated progress in legislative framework negotiations between key stakeholders. At the same time there have been impediments to all three projects due to delays in the permit process for the access of marine samples. The legislative framework is now progressing at the highest levels within the State Government and a biodiscovery Bill is expected to be introduced into WA State Parliament in 2012. Node 5 is in essence a proof-of-concept group of projects illustrating the potential outcomes that would flow on as a result of an implemented biodiscovery legislative framework operating in synergy with a fully collaborative initiative in marine biodiscovery and biotechnology.

Node: 5
Project: Western Australia Marine Bioresources Library (WAMBL)

Author: Jane Fromont
Collaborators: Libby Evans-Illidge, AIMS
Institution: Western Australian Museum
Email: jane.fromont@museum.wa.gov.au

Abstract

Bioresources are the raw materials for biodiscovery. High overheads, risks associated with collection and processing, ongoing collection management and curation, and maintenance of full legal compliance with access and benefit sharing obligations have been cited as major impediments to biodiscovery. Bioresources libraries help create an economy of scale to these overheads, and foster biodiscovery opportunity by facilitating legally certain access to samples, extracts, fractions and compounds. This project was developed in large part to deliver 'proof of concept' that a transparent and accountable system could be developed releasing Western Australian marine bioresources for biodiscovery research, until biodiscovery legislation was developed in Western Australia.

The original project objectives were as follows:

1 Establish a marine bioresources library to facilitate sustainable access to characterised Western Australian marine biodiversity for biodiscovery

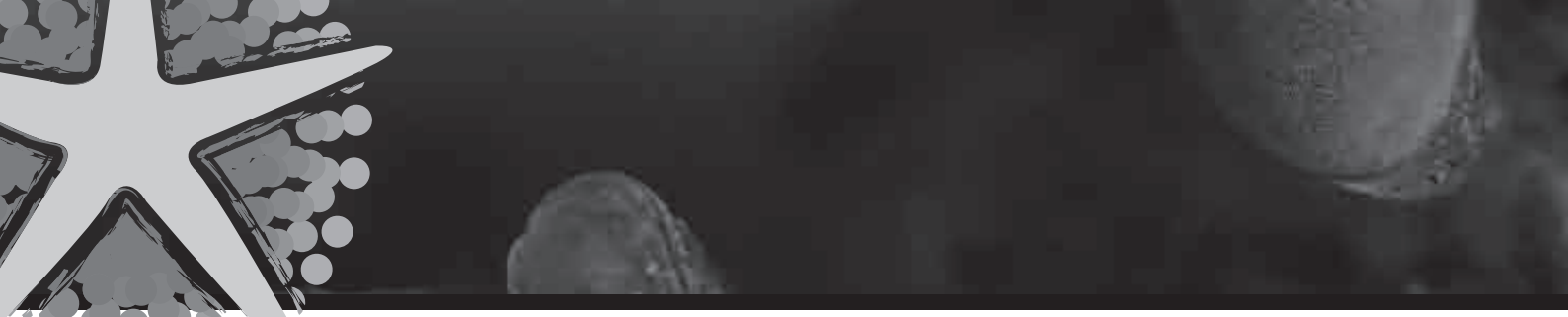
2 Establish standard operating procedures to access samples in the library in compliance with all access and benefit sharing provisions required by WA State government agencies, and WA Museum data capture requirements.

3 Maximise the capture of knowledge regarding Western Australian marine biodiversity that is made available for biodiscovery, and consolidate it at the Western Australian Museum in a format that is accessible to the State's natural resource managers.

4 Identify ways that the Western Australian Marine Bioresources Library could be maintained and expanded after the completion of WAMSI.

This project has established a library of specimens in WAMBL which currently contains 230 frozen Commonwealth and State collected samples. 466 frozen samples with extracts, collected from Western Australian waters are virtually incorporated i.e. they are held at AIMS in Townsville but have been 'signed over' to WAMBL which is now their only release point for biodiscovery research. Only specimens with acceptable provenance and storage conditions since their collection have been incorporated into WAMBL. A database of the WAMBL material includes all collecting data including georeferencing of locations and depths. Project metadata is available via IVEC, and the WAMBL sample data will be available via the WA Museum website once the project is completed (end 2011).

The project began in July 2009 and operating procedures to access material from WAMBL for biodiscovery purposes were established in December 2009, but samples for research were not released until October 2010, reflecting the significant difficulties associated with undertaking this type of research in Western Australia. Currently, two lots of samples and extracts have been released for biodiscovery, and two additional proposals to access material are currently being processed. The operational procedures and Material Transfer Agreement (MTA) have been drafted such that they can continue to be used when Biodiscovery Legislation is introduced in Western Australia.



Node: 5
Title: Biomolecular Diversity and Partnered Biodiscovery

Author: Peter Leedman
Collaborators: Viki Russell (WAIMR), Dr Jane Fromont (WAM), Prof Chris Battershill (AIMS), Dr Libby Evans-Ilidge (AIMS)
Institution: WAIMR
Email: petrel@waimr.uwa.edu.au

Abstract

The goal of this biodiscovery project was to perform proof-of-principle studies on a carefully selected group of marine samples in order to identify ones that have novel anticancer properties. This is an area of significant interest world-wide, as some marine-derived compounds are now entering early phase clinical trials in patients with cancer. So the precedent is a good one, and as WA has such unique and diverse marine organisms, the project holds great promise.

However, a major issue in this node was the delay (years) in obtaining access to the samples, due to regulatory issues. Approval was finally granted in late 2010 (over 2.5 years late) to access the samples for evaluation.

Fifty compounds isolated from up and down the WA coast were carefully selected by Prof Batershill and Dr Evans-Ilidge for potential anticancer activity based on an intimate knowledge of the marine organisms and Prof Battershill's experience in the mining of other organisms with a collaborator at the NIH in the USA.

These samples were provided by AIMS to Dr Jane Fromont from the WA Museum, who delivered them to the Leedman laboratory in WAIMR (Western Australian Institute for Medical Research) as freeze dried preparations. They were then dissolved predominantly in methanol and used in cell proliferation assays to determine the IC50 of growth inhibition of two different human cancer cell lines (LNCaP, human prostate cancer; MCF-7, human breast cancer).

We found that a significant number of samples have anticancer activity with IC50s of 0.3-10 micromolar range. Interestingly, there are samples with strong activity against prostate cancer and not breast cancer cell proliferation, and vice versa. In addition, we found to two samples with activity against both cell lines.

These positive hits are now undergoing subfractionation and iterative rounds of purification guided by activity in the assays (usually about 4 rounds) until we arrive at a pure compound.

In summary, these data provide evidence that WA marine organisms have potential anticancer activity, and supports further examination of these sites for further experimentation and exploration.

Node: 5

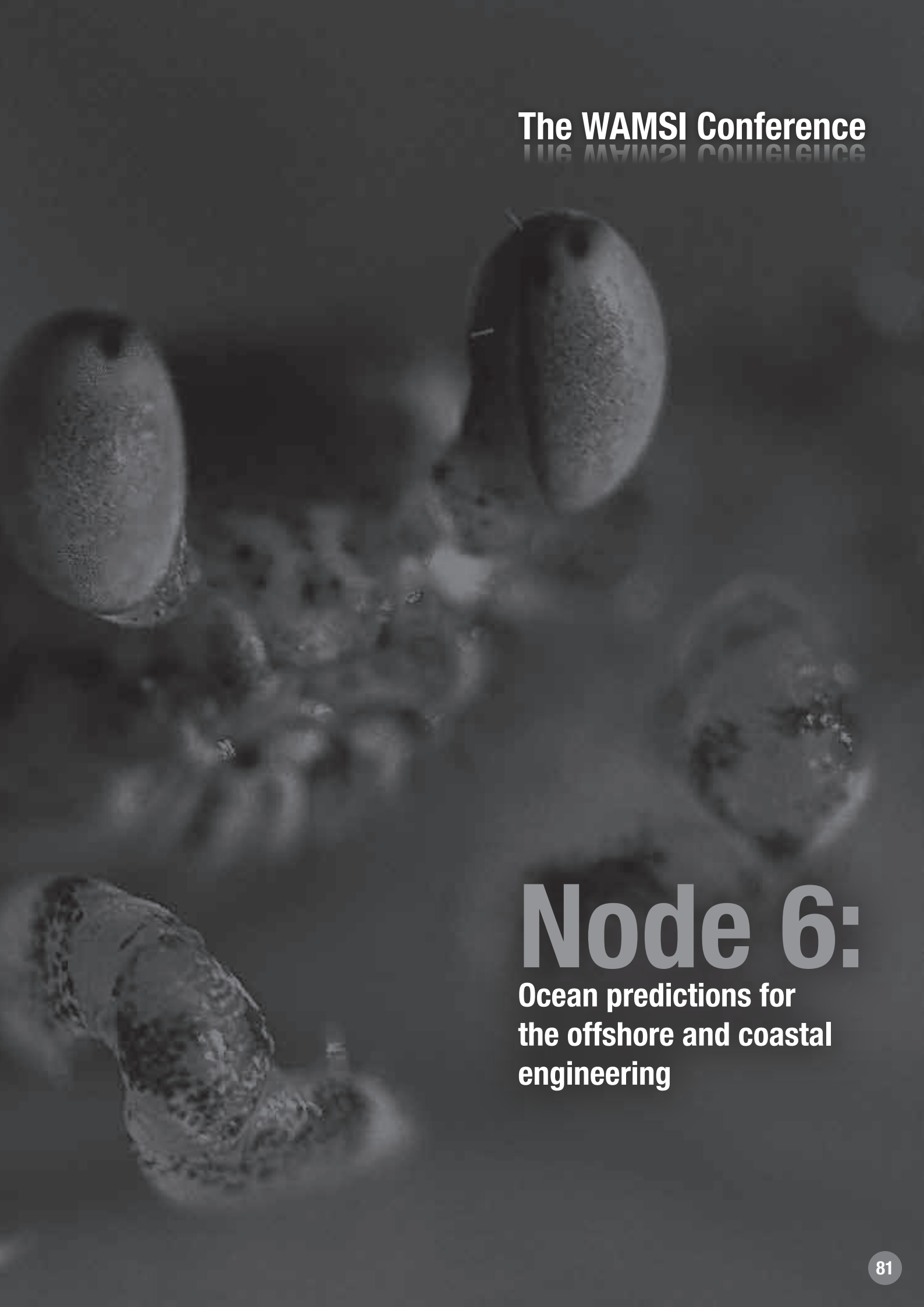
Title: A search for marine bacterial quorum quenching compounds

Author: Jamie Summerfield
Collaborators: A. Prof David Sutton, Prof. Barbara Chang, Prof. Emil Ghisalberti, Dr Gavin Flematti
Institution: University of Western Australia
Email: summej02@student.uwa.edu.au

Abstract

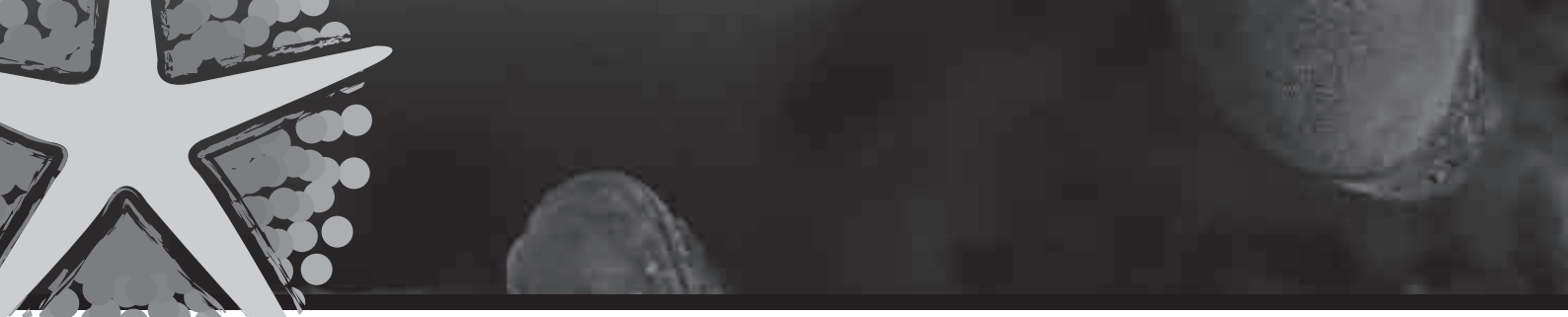
Antibiotic resistance is of enormous concern in disease control and is one of the factors driving the search for new strategies for controlling bacterial growth. One such strategy is quorum sensing inhibition. Quorum sensing (QS) is a bacterial communication process that allows control of gene expression in relation to cell density. Bacterial activities under QS control include the production of pigments and toxins, bioluminescence, swarming motility and biofilm formation. Quorum quenching (QQ) compounds inhibit the QS process, with the potential to control detrimental bacterial activities. QQ compounds have been isolated from several plants, algae, fungi and several bacteria. Marine invertebrates are known for the production of diverse novel bioactive compounds, many of which could be produced by symbiotic marine bacteria. The aim of this project was to isolate and characterise QQ compounds from marine bacteria.

Bacteria producing compounds that inhibited bioluminescence of the bacteria *Vibrio harveyi* were isolated from marine waters in the Perth metropolitan area. The isolated bacteria represented 9 different genera. Two of the isolates that strongly inhibited bioluminescence were selected for characterisation of their QQ ability. Extracts of these isolates inhibited bioluminescence of *V. harveyi* in a concentration-dependant manner without inhibiting growth, indicating that the bioactive compounds had potential QQ activity. The extracts also inhibited pigment production of *Serratia marcescens* and *Chromobacterium violaceum* which are both QS processes. The bioactive compounds in the extracts were purified and identified as desferrioxamines G and E. Pure forms of several desferrioxamines were purchased and the bioactivity of the pure compounds was confirmed. Pure desferrioxamine was assessed for QQ ability in multiple bacteria but was found to only inhibit QS processes in *V. harveyi* strain Vh1, indicating that desferrioxamine was not a broad spectrum QQ compound. Desferrioxamines can bind iron with high affinity and bacteria can take up and use this iron. The interactions between QS and iron regulation are complex, so it is possible that desferrioxamines do not inhibit QS directly, but may interfere with QS through interactions with iron and the iron regulation process.



Node 6:

Ocean predictions for the offshore and coastal engineering



Node: 6
Title: Node 6 Leader's Overview

Author: Greg Ivey
Institution: University of Western Australia
Email: Greg.Ivey@uwa.edu.au

Abstract

The research plan of Node 6 was to understand, quantify and predict the physical oceanographic processes operating on the North West Shelf for the benefit of the offshore industry, for the coastal engineering industry, and for the community. A major driver of the research is recognition of the research needs of the offshore oil and gas industry in the Western Australian marine environment. The research tools and model outputs from the Node are of direct relevance to offshore oil and gas industry and coastal engineering, to the fisheries industry, environmental issues, national strategic issues, and training/capacity building for the future. As the oil and gas industry has its primary focus on the North West Shelf (NWS), this is the only Node in WAMSI with primary focus on the marine waters from North West Cape to the Timor Sea. Some of the projects in Projects 6.1 and 6.3, in particular, extend to more southerly parts of the WA marine environment.

The 3 integrated projects in the node are:

6.1 Offshore and coastal engineering and the effects of climate change.

6.2 Impact of tides and internal waves on offshore engineering.

6.3 Ocean glider deployment as part of the West Australian Integrated Marine Observation System (WAIMOS).

The main findings from these projects will be summarized.

Node: 6

Title Storm surge climatology and sea level variability for Western Australia

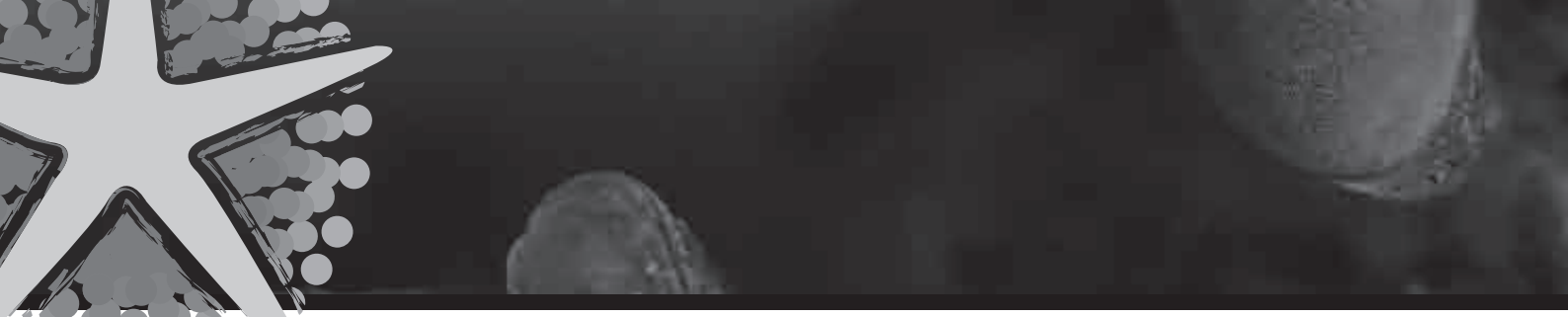
Author: Ivan Haigh, Matthew Eliot and Charitha Pattiaratchi
Collaborators: WA Departments of Transport and Planning
Institution: The University of Western Australia
Email: haigh@sese.uwa.edu.au

Abstract

When extreme sea level events occur along low-lying coastlines that are highly populated and/or developed, the impacts can be devastating, including: considerable loss of life; billions of dollars worth of damage; and drastic changes to coastal landforms. As a society, we have become increasingly vulnerable to extreme high sea levels due to the rapid growth in coastal populations and the accompanied increase of investment in infrastructure at the coastal zone. The occurrence of major coastal floods in the last decade such as those arising from hurricanes Katrina, Sidr and Nargis and more recently in the case of Australia, tropical cyclone Yasi, have dramatically emphasized the damage that can be caused by extreme sea level events, particularly when combined with the rise in coastal population.

Extreme sea levels arise as a combination of four main factors: mean sea level, tide, storm surge and waves. Over the last 150 years, global mean sea levels have on average risen by about 20 cm and it is predicted that this rise will continue over the 21st century and beyond, at an accelerated rate. With rises in sea level, given water levels will be exceeded more and more frequently as progressively less severe storm conditions are required to achieve that water level. In some coastal regions extreme high sea levels could be amplified further by variations in the strength and tracks of weather systems, such as more intense tropical cyclones, which will alter the magnitude, duration, and intensity of storm surges and waves. Another major aspect of interest is determining the coastal response due to the combined action of mean sea level rise, storm surge and waves, particularly under a changing climate.

The overall aim of this presentation is to examine how the individual components of sea level (exclusive of waves which will be considered in a presentation by Cyprien Bosserelle) and the combined extreme sea levels, are likely to change along the coastline of Western Australia during the 21st century. As a first step to considering future conditions, an assessment has been made of the historic changes in extremes throughout the 20th century to set projected 21st century changes in an appropriate context. Knowledge of both the historic and potential future changes in extreme events will help determine the scale and resources required for improved flood risk management, including upgraded coastal protection. Building on this work, Shari Gallop and Cyprien Bosserelle will consider the impact of these past and potential future changes in sea level on coastal stability around the coastline of Western Australia.



Node: 6
Title: Evolution of an extreme wave event from the ocean to the beach

Author: Cyprien Bosserelle
Collaborators: Shari Gallop Charitha Pattiaratchi, Ivan Haigh
Institution: School of Environmental Systems Engineering & the UWA Oceans Institute
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Abstract

Wave climate plays a key role in controlling the dynamics of sediment on Western Australian beaches. Even a subtle change in the wave climate can have significant repercussions on beach dynamics. Extreme wave events are particularly damaging, and it can take years before a beach recovers from storm erosion.

In this study, the evolution of an extreme wave event was followed through a cascade of scale using numerical models. The formation of the July 2009 extreme wave event was tracked on an ocean scale and then waves were followed as they transformed within the nearshore and the surfzone where they finally dissipated. Sediment transport and morphology of the beach were simulated in the nearshore scale and the potential erosion assessed.

Modelling results show that the erosion processes were similar to what was recorded during the 2009 event. Therefore the methodology used is adequate for assessing storm erosion. The role of extreme sea level and mean sea level rise on the storm erosion will be discussed.

Node: 6

Title: Perched morphodynamics : sea breezes, storms and seasons

Author: Shari L. Gallop
Collaborators: Cyprien Bosserelle, Charitha Pattiaratchi, Ian Eliot and Ivan D. Haigh
Institution: The University of Western Australia
Email: gallop@sese.uwa.edu.au

Abstract

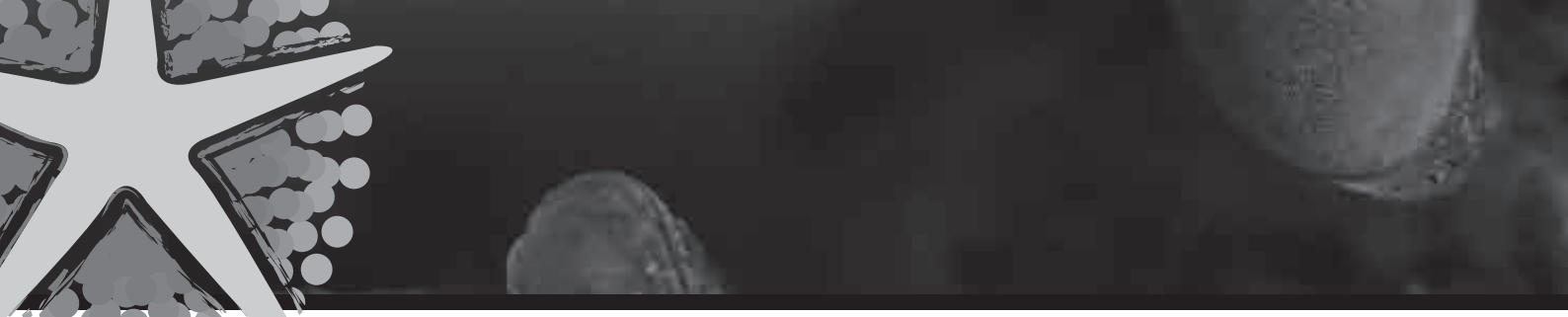
Accelerated sea level rise and possible changes in storminess and wave climate in the 21st century could have devastating effects on the coast. Of Australia's 10,685 beaches, 1044 are classified as 'perched' – where unconsolidated sediments have accumulated behind or on top of hard structures. In Western Australia, perched beaches are widespread, from the wave-dominated calcarenite beaches in the south to the tide-dominated beaches in the north that are fringed by coral reefs. Intuitively, perched beaches will respond differently to non-perched beaches to projected sea level rise and other changes in weather patterns driven by climate change. To predict the behaviour of perched beaches, we need to understand how they respond to each component of the hydrodynamics, from waves and currents, through tides and storm surge, to mean sea level. Therefore, we aim to quantify how hard-structures on perched beaches influence the response of the beach to metocean forcing over a cascade of temporal and spatial scales. To achieve this, we focused on Yanchep Lagoon, located 60 km north of Perth in the microtidal, southwest Western Australia where the beach consists of well-sorted medium sand. The beach is perched on the Pleistocene Tamala Limestone formation and the rock topography varies alongshore. The northern and southern sections of the beach are separated by a small headland made of limestone. The southern section is fronted by a limestone bluff that supports the dry beachface while the southern section is fronted by an intertidal reef which encloses a coastal lagoon. An intensive programme of field work measuring beach morphology and hydrodynamics was undertaken over a range of scales:

(1) Meso-scale changes over hours-days
   a. during the strong sea breeze season in summer, for one week in February 2010
   b. during the winter storm season for one week in July 2010

(2) Macro-scale changes between seasons using monthly beach surveys

(3) Mega-scale changes in beach width since 1941 in relation to each component of the hydrodynamics including waves, tides, storm surge and mean sea level indices developed by I.D. Haigh and C. Bosserelle.

Results indicate that the rock formations have a strong influence on the beach behaviour over all scales. During sea breeze and storm activity, there was extreme spatial variation in the beach behaviour. While rock formations can provide a degree of beach protection, they can also hinder beach recovery. There was a seasonal cycle of erosion and accretion at Yanchep lagoon, but the northern and southern sections of the beach were inversely correlated. In summer, the southern section accreted as wind-waves generated by the sea breeze suspended sediment and washed it over the limestone bluff to infill the lagoon. This blocks the main sediment transport pathway to the northern section and caused it to erode. Conversely, in winter as swell waves caused erosion of the southern section the northern section accreted as the sediment transport pathway was re-opened. Inter-annual changes in beach widths appear to be driven by the intensity of the sea breeze season. The relationship between inter-annual beach widths to each component of the dynamics varied alongshore with rock topography. Therefore, rock formations have a strong influence on the morphology of perched beaches on a range of temporal and spatial scales.



Node: 6
Title: Internal wave dynamics and climatology at Ningaloo Reef

Author: Nicole L. Jones[1]
Collaborators: Gregory N. Ivey[1], Richard Brinkman[2], Ryan J. Lowe[1], Cynthia E. Bluteau[1], James L. Falter[1], Matthew D. Rayson[1] and Samuel M. Kelly[1].
Institution: [1]University of Western Australia
[2]Australian Institute of Marine Science
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Abstract

At Ningaloo Reef, physical processes such as transient upwelling and non-linear internal waves have been identified as possible mechanisms for the delivery of nutrients from depth to the euphotic zone. We have used six years of acoustic Doppler current profiler and thermistor string data and additional data from an intensive experiment in summer 2009/2010 to examine the characteristics of the internal wave field on the steep slope of Ningaloo. The internal waves steepened as they propagated inshore, often becoming highly non-linear. The long-time series allowed identification of both seasonal and inter-annual variation in the internal wave climatology. Internal waves more consistently propagated inshore during the warmer months when the mixed layer depth was quite shallow. However, during the cooler months, when the water column was well mixed to depths of around 100 m, highly non-linear internal boluses intermittently transported sub-thermocline water up the slope. There was noticeable inter-annual variation in both the occurrence and the strength of the internal boluses. During the summer, the mesoscale flows modified the internal wave response. During the upwelling period in 2009 there was a high occurrence of bores. The bores led to the net onshore transport of nitrate and phosphorus by internal waves. During the downwelling period in 2009 there was a net offshore flux of nitrate and phosphorus.

Node: 6

Title: Turbulent mixing in bottom boundary layers forced by internal waves

Author: Cynthia E. Bluteau
Collaborators: Nicole L. Jones and Gregory N. Ivey
Institution: The University of Western Australia, School of environmental Systems Engineering and the UWA Oceans Institute
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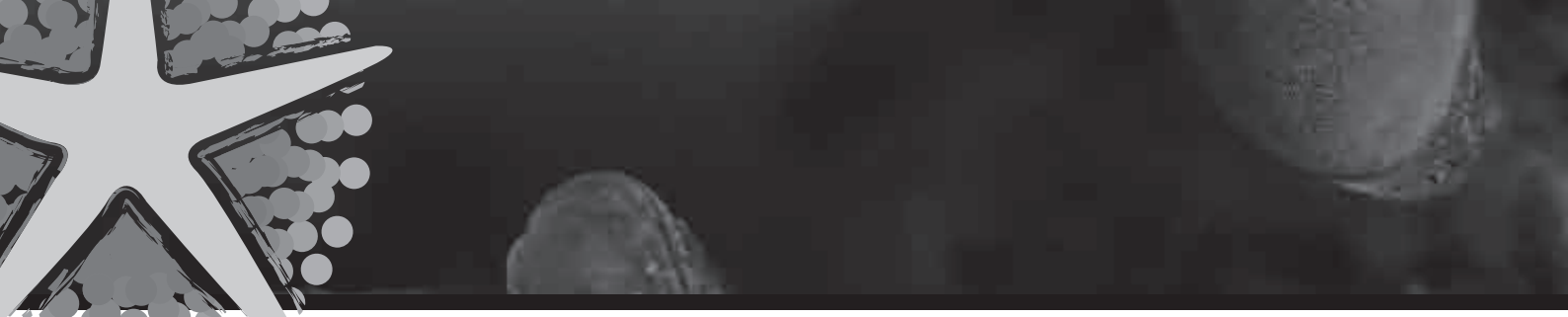
Abstract

We present observations from diverse sites on the Australian North-West Shelf, known for its ubiquitous internal wave activity. Mean velocities and temperature profiles were collected (over depths 75-400 m) to document the background barotropic tidal forcing, stratification N and the internal wave characteristics. We also measured high frequency (1-2 Hz) temperature and velocity to quantify turbulence properties in the near-bottom region, where motions with characteristics similar to internal bores or boluses propagated onshore during the flood phase of both spring and neap tides. The arrival time of the internal bores at the measurement sites varied amongst tidal cycles and their characteristics were not highly correlated with the amplitude of the barotropic forcing. The passage of the internal bores was associated with large turbulent overturns, enhanced turbulent kinetic energy dissipation ($>10^{-6}$ W/kg) and intensified currents (40 cm/s i.e., >6 times the barotropic forcing) within meters of the seabed. Stratification and shear competed to govern our observed overturning length scale ($\leq$ 4 m) that were characterized by the Ellison length scale L_E. Only measurements closest to the seabed (1.7 m) were described by the log law-of-the-wall; generally both buoyancy and the presence of the bottom boundary influenced L_E, while sometimes flow-induced shear determined L_E. Overall, a more general descriptor of the overturning length scale is necessary for complex stratified shear flows. Mixing efficiencies (and hence eddy diffusivities) were also an order of magnitude smaller than 0.2 typically used with Osborn's model to predict mixing rates.



Node: 6
Title: Ocean Dynamics of the Browse Basin and Scott Reef

Author: Matt Rayson
Collaborators: Gregory Ivey, Nicole Jones, Michael Meuleners, Geoffrey Wake, Oliver Fringer
Institution: University of Western Australia
Email: rayson@sese.uwa.edu.au

Abstract

We investigated the tidally-driven ocean dynamics on the continental shelf and slope offshore of the Kimberley region using a combination of field measurements and numerical modelling. At a regional scale, the extremely large barotropic tide interacts with the complex topography in the Browse Basin, generating internal gravity waves which propagate away from their source region, dissipating energy and causing mixing in places remote to the generation site.

Internal wave generation occurred at a number of discrete topographic features and the resultant interaction of multiple waves led to a spatially variable internal wave climate. At a local scale, the tidal flow interacts with topographic features of small horizontal length scale (~O(1) km), such as Scott Reef, generating highly energetic and nonlinear flow features such as jets, eddies and internal hydraulic jumps. These flow features created localised regions of enhanced mixing and are therefore likely to be important for the transport and dispersal of nutrients and other material to biological systems.

Node: 6
Title: Ocean glider deployments in WA – an overview

Author: Chari Pattiaratchi
Collaborators: Ben Hollings, Christine Hanson, Mun Woo, Dennis Stanley
Institutions: The University of Western Australia, CSIRO, AIMS
Email: chari.pattiaratchi@uwa.edu.au

Abstract

Oceanographic sampling has been traditionally undertaken using ships; however the high costs of operating a research vessel of the order of $50,000 per day and limitations of working in adverse weather conditions have resulted in difficulties in data collection in particular where sustained observations are required to examine long-term variability. Ocean gliders provide an alternative measurement platform and, due to their relatively low cost and extended deployment durations, allow for the collection of sustained long term observations, even during periods of extreme weather conditions. These data sets enable researchers to document the natural variability of the ocean and coastal ecosystems. The Australian National Facility for Ocean Gliders (ANFOG) has been set up as facility within the Australian Integrated Marine Observation System (IMOS) and provides a near-real time data stream from the continental shelf and slope waters along Western Australia. Ocean gliders are autonomous vehicles designed to operate in water depths up to 1000 m. By changing its buoyancy, the glider is able to descend and ascend. This momentum is converted to forward motion by its wings. Pitch adjustments are made by moving an internal mass (battery pack) and steering is done using a rudder and/or battery packs. Moving at an average horizontal velocity of 0.25 – 0.40 ms^{-1} the glider navigates its way to a series of pre-programmed waypoints using GPS, internal dead reckoning and altimeter measurements. The gliders are programmed to provide data through satellite communication when it is at the surface and it is also possible to control the path of the glider during its mission. Depending on the type of glider and the number of vertical 'dives', the endurance of a glider ranges between 1 and 6 months. Glider deployments were undertaken along the west coast with almost monthly Slocum glider transects off Two Rocks since January 2009 and supplemented by Seaglider deployments between North-west Cape and Rottnest Island to sample the Leeuwin current system.

One of the major highlights of the program was the discovery of Dense Shelf Water Cascade (DSWC) along the Rottnest continental shelf. Dense shelf water is formed when the density of the inner shelf water is increased either due to a decrease in temperature through cooling and/or an increase in salinity due to either evaporation or ice formation. This water is transported along the sea bed across the continental shelf as a near bed current which is defined as Dense Shelf Water Cascade. The ocean glider data revealed that the DSWC was a regular occurrence along the Rottnest continental shelf, particularly during autumn and winter months. In autumn, the dense water is mainly formed through changes in salinity resulting from evaporation, whilst in winter; temperature change through surface cooling was the dominant factor. The mean wind speeds also decreased during the transition in autumn. The speed of the DSWC was estimated to be 0.01-0.02 ms-1 similar to that measured in other selected regions globally. The offshore transport from the shelf is a significant component of the alongshore wind-driven transport.

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