western australian
marine science institution

better science better decisions

2015 WAMSI Research Conference

Proceedings

Perth, Western Australia, 30 March – 1 April 2015

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Cover image: Hans Kemps - nudibranch Halgerda sp on yellow sponge

Introduction

This year's research conference will deliver progress updates and latest findings from more than 50 WAMSI projects being delivered by its partner organisations forming part of two of the largest marine research programs in Australia.

Among the keynote speakers;

- **EPA Chairman Paul Vogel** will discuss science, knowledge and managing risk through environmental impact assessment;
- **Woodside Energy, Senior Vice President Science and Technology, Shaun Gregory,** will provide an industry perspective on strategic marine science;
- **WA Chief Scientist Peter Klinken** will present his views on the State's research focus; and
- **WAMSI CEO Patrick Seares** will present an overview of research progress, future direction and initiatives to improve collaboration on information.

Over the course of the three day conference, lead researchers and industry representatives who are working with WAMSI on the Kimberley Marine Research Program and the Dredging Science Node will provide updates on the foundational research supporting these programs including:

- Reports on the most up to date information available for use in dredging operations and management; and
- Key findings and future direction for marine research being carried out for the first time in the unique conditions that exist off the Kimberley coast

As part of the conference, Western Australian Premier and Minister for Science Hon. Colin Barnett MLA is launching the WA Blueprint for Marine Science 2050.

The Blueprint is an important initiative that aims to help government, research institutions and industry to better plan and collaborate on the priority marine research needed to support the future prosperity of WA and the nation.

The recommendations are the culmination of comprehensive consultation focusing on the end users of research, business, industry, government and community groups brought together by an independent steering group led by renowned scientist and advocate for collaborative research, E/Prof Alistar Robertson.

More information including conference schedule updates, abstracts and audio/PowerPoint presentations will be made available on the WAMSI Conference 2015 webpage.

Thank you for your participation..

Naomi Brown

Chair WAMSI

2015 WAMSI Conference

Monday 30 March – Wednesday 1 April 2015

State Library of Western Australia, Perth

Day 1 – Monday 30th March 2015

Time	Presentation	Speaker
Session 1, Chair: Patrick Seares **Opening and keynote presentations**		
Time	**Presentation**	**Speaker**
9:00	Introduction and Welcome to Country.	Theresa Walley
9:20	WAMSI – summary of progress and future directions.	Patrick Seares, WAMSI CEO
9:40	Keynote Presentation – Building a Science and Knowledge base for Environmental Impact Assessment.	Paul Vogel, EPA, Chairman
10:10	Opening the 2015 WAMSI Research Conference.	Hon. Donna Faragher MLC. Parliamentary Secretary to the Premier; Minister for State Development; Science
10:20	Keynote Presentation - Science priorities for Western Australia.	Peter Klinken, Chief Scientist of Western Australia
10:35	Morning Tea	
Session 2, Chair: Patrick Seares		
11:00	Keynote Presentation – an industry perspective on strategic marine science.	Shaun Gregory, Woodside Energy, Senior Vice Pres. Science and Technology
11:20	Initiatives to improve collaboration on information, wildlife and estuaries.	Patrick Seares, WAMSI CEO
11.40	The role of science in conservation management.	Margaret Byrne, Department of Parks and Wildlife

11:55	Management Based on Science: Applying Learnings from Gorgon to the Chevron Wheatstone Dredging Program.	Michael Marnane, Chevron
12:10	A QLD perspective on outcomes focused research for both dredging and marine park management.	Bruce Elliot, GBRMPA
12:30	**Lunch**	
Session 3, Chair: Dr Ross Jones **Dredging Node – Introduction & Themes 2 and 3 (Generation and Transport of Dredge Plumes)**		
13:30	Dredging Science Node Overview.	Ray Masini, OEPA
13:50	Invited Speaker: Dredging 101 – What are they, different types, how do they operate, what pressure fields do they generate?	Tim Green, BMT JFA Consultants
14:05	Theme 2 / 3 Overview, Generation and Transport of Dredge Plumes.	Graham Symonds, CSIRO
14:20	Generation and release of sediments by hydraulic dredging.	Des Mills, Marine Environmental Reviews
14:30	Redefining sediment transport models over sensitive benthic habitats.	Ryan Lowe, UWA
14:40	The light environment in turbid waters.	Peter Fearns, Curtin
14.50	Modelling Dredging Generated Sediment Plumes.	Graham Symonds, CSIRO
15:00	**Afternoon Tea**	
Session 4, Chair: Dr Ray Masini **Dredging Node – Themes 5 & 6 (Seagrass and Sponges)**		
15:30	Invited Speaker: Consultants perspective on WAMSI Dredging Science Node.	Ian Le Provost – Environmental Consultants Association.
15:40	Theme 5 Overview, Defining thresholds of primary producer response to dredge pressures.	Paul Lavery, ECU

16:00	Genetic variability, seasonal dynamics and recovery mechanisms of tropical seagrasses – update on field programs in north-west Australia.	Kathryn McMahon, ECU
16.10	Deriving pressure-response relationships of tropical seagrasses to dredge pressures – a laboratory approach.	John Statton, UWA
16:20	Theme 6 Overview, Defining thresholds of filter feeder response to dredge pressures.	Nicole Webster, AIMS
16:30	Observations from pre-dredging surveys of filter feeders at Onslow.	Muhammad Abdul Wahab, AIMS
16:40	Identifying, characterising and quantifying the effects of dredging on sponges (Porifera).	Brian Strehlow, UWA / AIMS
16:50	Deriving pressure-response relationships of sponges to dredge pressures – a laboratory approach.	Mari-Carmen Pineda, AIMS

Day 2 – Tuesday 31st March 2015

Session 1, Chair: Kevin Crane **Dredging Node – Themes 4 & 7 (Corals and Coral Reproduction Windows)**		
9:00	Invited Speaker: Industry perspective on WAMSI Dredging Science Node.	Luke Smith - Woodside
9:10	Theme 4 Overview, Dredging and Corals.	Ross Jones, AIMS
9:20	Specific and interactive effects of total suspended solids, light attenuation and sediment deposition on adult corals.	Alan Duckworth, AIMS
9:30	Turning data into management recommendations: Predicting coral mortality based on water quality during dredging.	Rebecca Fisher, AIMS
9:40	Measuring sediment deposition during dredging programs: development of an in situ deposition sensor.	James Whinney, JCU
9:45	Measuring sediment deposition during dredging programs: modelling approaches.	Clair Stark, JCU
9.50	Theme 7 Overview, Effects of dredging on coral reproduction.	Andrew Negri, AIMS

10:10	Review of coral reproduction in WA and current state of knowledge.	James Gilmour, AIMS
10:20	Laboratory experimentation on the effects of dredging on fertilisation, larval development and settlement of corals.	Gerard Ricardo, AIMS
10:30	**Morning Tea**	
Session 2, Chair: Kevin Crane **Dredging Node Themes 8 & 9 (Environmental Windows for Finfish and Other Organisms)**		
11:00	Invited Speaker: Dredging in the Pilbara – Ports perspective.	Wayne Young, Pilbara Ports Authority
11:15	Theme 8 Overview, Effects of dredging related pressures on critical ecological processes for finfish.	Euan Harvey, Curtin
11:30	Theme 9 Overview, Effects of dredging related pressures on critical ecological processes for other organisms.	Gary Kendrick, UWA
11:45	Free time/networking opportunity for conference attendees. Dredging Science Node meeting for DSN researchers (closed session).	All
12:30	**Lunch**	
Session 3, Chair: Stuart Field **Kimberley Node – Understanding the history and habitats of the Kimberley**		
13:30	Kimberley Node Overview.	Stuart Field, DPaW
13:40	Invited Speaker: The Kimberley Environment.	Barry Wilson
14:10	Geomorphology.	Lindsay Collins, Curtin
14:25	Benthic Biodiversity.	Andrew Heyward, AIMS
14:40	Data Management.	Luke Edwards, WAMSI
14:50	Use of LIDAR in the Kimberley.	Mick O'Leary, Curtin
15:00	**Afternoon Tea**	

Session 4, Chair: Peter Thompson **Kimberley Node – Physical Processes and Primary Productivity – Feeding the System**		
15:30	Oceanography.	Greg Ivey, UWA
15:45	Biogeochemistry.	Matt Hipsey, UWA
16:00	Land-sea Linkages.	Andy Revill, CSIRO
16:15	Primary production.	Ryan Lowe, UWA
16:30	Seagrass and mapping productivity.	Gary Kendrick and Renae Hovey, UWA

Day 3 – Wednesday 1st April 2015

Session 1, Chair: Stuart Field **Kimberley Node – Managing Marine Resources and Values**		
9:00	Invited Speaker: Western Australia's Kimberley marine parks and WAMSI.	Tom Hatton
9:20	Invited Speaker: Partnering with Indigenous Communities.	Daniel Oades, KLC
9:40	Patterns of Human use.	Lynnath Beckley, Murdoch
9:55	Social Values and aspirations.	Jennifer Strickland-Munro, Murdoch
10:10	Indigenous knowledge.	Albert Wiggan, Nyul Nyul Rangers
10:25	Management Strategy Evaluation.	Fabio Boschetti, CSIRO
10:40	**Morning Tea**	
Session 2, Chair: Andrew Heyward **Kimberley Node – Ecological Processes and Change in the Kimberley**		
11:00	Key ecological processes.	Mat Vanderklift, CSIRO
11:15	Climate Change.	Ming Feng, CSIRO

11:30	Calcification.	Verena Schoepf, UWA
11:45	Sediment Records.	John Keesing, CSIRO
12.00	Connectivity.	Oliver Berry, CSIRO
12:15 – 1:00 pm Special event: Launch of the Blueprint for Marine Science 2050 **Hon Colin Barnett MLA, Premier of Western Australia; Minister for Science** Chair, Independent Blueprint Steering Committee E/Prof Alistar Robertson WAMSI Chair – Naomi Brown (followed by coffee and discussion outside conference room)		
13.00	**Lunch**	
Session 3, Chair: Dr Kelly Waples **Kimberley Node – Marine Fauna and Developing Long Term Monitoring and Research**		
14.00	Invited Speaker: Fisheries Research in the Kimberley.	Brett Molony, DoF
14:15	Marine Turtles.	Scott Whiting, DPaW
14:30	Humpback Whales.	Michele Thums, AIMS
14:45	Crocodiles.	Andy Halford, DPaW
15:00	Dugongs.	Mat Vanderklift, CSIRO
15:15	**Afternoon Tea**	
15:45	Dolphins.	Lars Bejder, Murdoch
16:00	Shorebirds.	Danny Rogers, AWSG
16:15	Remote Sensing.	Peter Fearns, Curtin
16:30	Invited Speaker: WAMMP – KMRP research informing long term monitoring.	Andy Halford, DPaW
16:50	**Close of Conference and Closing Remarks**	Patrick Seares, WAMSI CEO

Abstracts

WAMSI – summary of progress and future directions

Patrick Seares

Western Australian Marine Science Institution

The Western Australian Marine Research Institution (WAMSI) has taken major strides towards delivering two of Australia's largest and complex marine research programs. WAMSI is also renewing its focus on creating the collaborative and strategic partnership between the research, industry and Government sector.

WAMSI is a joint venture of ten marine research, industry and Government organisations formed to build a collaborative and outcome focussed research sector, and deliver strategic multidisciplinary research programs.

From 2006-2011, the ~$60million first tranche of WAMSI research delivered outcomes that supported; the development of a new fisheries management system, definition of internal waves affecting offshore infrastructure, management of the Ningaloo World Heritage area, quantification of new major currents and ocean heatwaves and much more.

WAMSI, and Western Australia, is now benefitting from that enhanced capability through marine science generally, and also through two of the largest programs of marine research in Australia. The $19million Dredging Science node and the $30million Kimberley Marine Research Program will provide governments, industry, Traditional Owners and the community with important information about previously poorly understood marine environments and processes.

Supporting WAMSI's motto of "Better Science, Better Decisions", both nodes are delivering on knowledge transfer processes that will improve management and decision making.

WAMSI uniquely fills the space between research organisations, industry, and Government. Its independence and impartiality provide a 'safe place' to deal with issues while seizing on the opportunities to make research more efficient and delivering better outcomes to the community, Government and industry.

Building the partnership across sectors has become a key focus for WAMSI of late with several initiatives to build collaboration already underway, and the commissioning of the independent Blueprint for Marine Science 2050 which surveys the knowledge needs of end-users from six key sectors interacting with the marine environment. These exercises will help align efforts across sectors to improve the impact of marine research on future economic and environmental prosperity for Western Australia.

Building a Science and Knowledge base for Environmental Impact Assessment

Keynote Presentation

Dr Paul Vogel

Chair, Environmental Protection Authority of Western Australia

In simple terms the objectives of the Environmental Protection Authority (EPA) are to protect the environment and to prevent pollution and environmental harm. It does this primarily by providing independent advice to Government on a range of environmental matters, including the environmental acceptability of development proposals that have the potential to have a significant impact on the environment.

Environmental Impact Assessment (EIA) relies on proponents to predict the potential impacts and risks associated with their proposals. The EPA critically evaluates those predictions, taking into account the level of confidence that can be placed on them.

Dredging and construction of marine infrastructure has been a key issue for the EPA during its assessment of recent large-scale coastal development proposals and the EPA's reports have highlighted predictive uncertainty as a major consideration. This uncertainty relates primarily to the impacts of dredging on marine habitats and the ecosystems they support, and the impact of construction and operations more broadly on marine fauna.

The challenges involved in predicting impacts and risks are in no small part due to the fact that WA has responsibility for a marine jurisdictional area that spans a range of climatic regimes and is over 117,000 km^2, including over 20,000 km of coastline and 3,700 islands and most of this domain has only been partly described scientifically, and even less well understood.

The EPA has taken a strategic view to tackling these knowledge problems, and looked at innovative ways to address them through a combination of science and policy. The EPA has high-lighted these issues in its Annual Reports to Parliament and recognised the WAMSI initiatives in these important areas.

Although the EPA's role in EIA is generally understood, its role in encouraging and carrying out studies, investigations and research into the problems of environmental protection is less well known. In this presentation I will provide background to the issue from the perspective of the EPA's roles and responsibilities, what the Authority has been doing in both the science and policy space to facilitate improvements in these areas, and to reinforce the importance that it places on having a solid science and knowledge base to support best practice Environmental Impact Assessment.

Initiatives to improve collaboration

Patrick Seares
Western Australian Marine Science Institution

WAMSI is delivering several activities aimed at improving the collaboration within the research sector and between the research, industry and Governments sectors.

A Western Marine 'Knowledge Hub'

With so many participants undertaking research or assessment activities in the marine environment off Western Australia, there are opportunities for a more organised and cooperative approach to data collection, data management, research linkages and knowledge transfer. WAMSI will be bringing together State, Commonwealth, research and industry groups to identify opportunities for the Western Australian marine sector to be more effective in these areas to save money, enhance research and improve the flow of information to end-users and the community.

Exploring a Marine Wildlife Node

A better understanding of the risks facing protected marine wildlife has been stated as a priority in the independent Annual Report from the Western Australian EPA, and has been the basis of hundreds of projects by research institutions and consultants funded by industry and governments. A WAMSI working group has completed a preliminary scan of marine wildlife projects off WA, and State Government priorities, as a step towards identifying the case for a more collaborative approach to marine wildlife studies off Australia's western coast.

Agreed knowledge priorities for south western estuaries

With substantial climate and development challenges facing south western estuaries, it is important that limited research investment and capability is focussed on providing the answers that managers and policy makers will need in the future. WAMSI, with the Swan River Trust and Department of Water, has run surveys and a major workshop to develop common priorities for new knowledge that are supported by both managers and researchers. This process seeks to align research with these priorities and improve impact through better interaction between managers and researchers.

Other activities include:

- Formalising associate partnerships with IMOS to simplify engagement with the same community
- Commissioning the PROSPER report to gauge industry support for a shared observing, modelling and data management system in the Pilbara
- Supporting the trials of the industry led I-GEMs initiative

The role of science in conservation management

Dr Margaret Byrne

Department of Parks and Wildlife

Western Australia's diverse marine environment stretches across temperate, sub-tropical and tropical regions, from the rugged south coast to temperate west coast reefs and seagrass meadows in Shark Bay, to the iconic Ningaloo Reef and the wild Kimberley. Western Australian locals and visitors alike treasure the natural heritage and resources of our marine environment, which is home to a number of iconic species, such as whale sharks, marine turtles, whales, dolphins and dugongs, and supports a number of important industries.

The Western Australian Government, through the Department of Parks and Wildlife, is committed to a world class marine parks and reserves system. Since 2008, the Western Australian Government has created new marine parks on the south coast at Walpole, along the south-west Capes and in the Kimberley region and has committed to further new marine parks that will more than treble the area protected from approximately 1.5 million hectares to around 5 million hectares.

A sound understanding of natural values, and the ecological processes that support them, is vital to underpin effective management of these natural areas in a multiple use context. Parks and Wildlife, through the Marine Science Program and in partnership with institutions such as WAMSI, undertakes strategic research and monitoring programs designed to improve on-ground management of the marine environment, and draws on the outcomes of strategic marine research programs. The previous WAMSI Ningaloo Research Program and the current WAMSI Kimberley Marine Research Program are focused on key marine parks providing baseline physical, biological and cultural information that will assist in effective marine park management. Parks and Wildlife is also working with Aboriginal traditional owners, particularly in the Kimberley, to develop and implement joint management of the marine environment that recognises traditional cultural needs alongside conservation, tourism and industry.

Management Based on Science: Applying Learnings from Gorgon to the Chevron Wheatstone Dredging Program

Dr Michael Marnane

Chevron

Collaborator: Dr Travis Elsdon

Large, capital dredging campaigns in Western Australia have traditionally been managed based on the monitored health of receptors. However, this approach is largely reactive - management is initiated only after an impact has occurred - and response is typically slow due to the time taken to collect data. An approach based on telemetered water quality data can allow a more rapid and proactive response. However, a limited understanding of the relationship between water quality and receptor health has, in the past, led to reluctance to use this approach, since overly conservative water quality triggers can cause unnecessary and costly management of dredging while non-conservative triggers may allow unwanted impacts to occur.

During the Chevron Gorgon dredging program, an unprecedented amount of data was collected on water quality and coral health. Water quality was monitored continuously at 36 sites and the health of ~1600 individually labelled corals was measured fortnightly over 18 months. While fortnightly reports were produced for compliance purposes, a significant investment was also made by Chevron in a “Predictive Links” program, which involved a re-analysis of data to better understand the relationship between water quality and coral health. This additional investment allowed derivation of water quality thresholds for corals that were uniquely based on field measurements during a dredging program rather than laboratory experiments.

The nearby Chevron Wheatstone dredging program capitalised on the outputs from Gorgon Predictive Links. Water quality management triggers were developed for Wheatstone that were aligned with thresholds and response times of corals and accounted for variability in metocean conditions and dredge plumes. During Wheatstone dredging, water quality data were telemetered in near-real time to allow daily comparisons against these triggers. Monitoring of receptors was still undertaken, albeit less frequently than for Gorgon, to verify that water quality triggers were affording appropriate levels of protection and allow for adaption, if required. The resultant proactive and adaptive management program provides a leading example of how science can enhance the environmental management of development projects.

Outcomes focussed research for dredging and marine park management: a Great Barrier Reef perspective

Dr Bruce Elliot

Great Barrier Reef Marine Park Authority

The Great Barrier Reef is an Australian icon and a world heritage property, recognised internationally for its outstanding universal value. Containing a maze of reefs and islands, it stretches more than 2300 kilometres along the Queensland coast and is the world's largest coral reef ecosystem, rich in biodiversity.

It is critical to the cultural, economic and social wellbeing of the more than one million people who live in its catchment, and is valued by the national and international community. It is a marine protected area, conserving the Reef's environment and supporting a wide range of activities, including tourism, fishing, recreation, traditional use, research, defence, shipping and ports. The Reef's environment helps bring billions of dollars to Australia's economy each year and supports almost 70,000 jobs.

The challenges facing the Great Barrier Reef have changed over the decades and so has management of the area. In recent years, the focus on addressing impacts from land-based runoff and coastal development has heightened. In particular the need to effectively manage large capital dredging projects to support the expansion of ports to increase capacity for exports has drawn extensive media and commentary.

In this time the Great Barrier Reef Marine Park Authority has targeted efforts at improving the knowledge base around the impacts of dredging and the disposal of dredge material at sea. Improvements in knowledge have led to the development of better information for environmental impact assessments of projects.

There are also new technologies and innovations being developed that may provide alternatives to the disposal of dredge material at sea into the future.

This presentation will provide an overview of how science is improving management of dredging and disposal of dredge material from Great Barrier Reef ports.

Dredging Science Node Overview

Ray Masini

Office of the Environmental Protection Authority

The Dredging Science Node is funded by environmental offsets from three different projects and the pooling of these funds has enabled a quantum of work that would not be possible if each offset was implemented independently and in isolation.

With a greater that 1:1 co-investment from WAMSI research partners, the value of the science program exceeds $19 million and involves more than 50 scientists working to implement a science plan designed to enhance the capacity within both government and the private sector to predict and manage the impacts of dredging.

The research is largely 'applied' in nature and designed to address key areas of uncertainty associated with the environmental impact assessment and management of marine dredging proposals. In addition to the straight science products, the outputs of the Node will include specific guidelines and protocols for prediction and management that will be packaged as a freely available virtual 'compendium of best practice'. Access to environmental data collected by Industry before, during and after dredging is critical to the success of the program. These data are recognised as being extremely valuable both in dollar terms and because they provide actual measurements of the pressures and environmental responses to various combinations of dredges, substrates and biota and as such can be used to validate and refine the guidelines and protocols over time.

The form and content of the compendium will be designed to complement the Environmental Assessment Guidelines for dredging that are used in WA and elsewhere to provide clarity and consistency in the assessment of marine dredging proposals. As such they will be of particular interest to project proponents and their environmental consultants and the Node will be engaging with these groups through the Dredging Science Advisory Committee to ensure the outputs are relevant and fit-for-purpose.

The initial focus is on the tropical regions of WA, but the findings from this important initiative will have broader relevance around Australia and internationally.

This presentation with provide a brief overview of the structure of the Node and its science plan, how the outputs link to the contemporary policies and are designed to meet the objective of improving our collective ability to predict and manage the impacts of dredging in Western Australia and beyond.

Dredging 101: Why, Who, How and So What

Invited Speaker

Tim Green

BMT JFA Consultants

This presentation will provide a pictorial snapshot of the basics of dredging. It will cover the need for dredging ("why"), the dredging industry ("who"), the types of dredging plant ("how") that are deployed on projects in Western Australia and comparative scale of our projects ("so what").

The presentation will discuss the factors affecting selection of preferred dredging equipment for projects, how that equipment operates and associated constraints with it and the primary dredge plume pressure fields associated with them.

Predicting and measuring the characteristics of sediment plumes due to dredging operations

Graham Symonds[1,4]

Collaborators: Ryan Lowe[2,4], Peter Fearns[3,4]

Institutions: [1] CSIRO, [2] UWA, [3] Curtin University, [4] Western Australian Marine Science Institution

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Quantifying and modelling the transport and fate of sediments released during dredging operations is essential to predicting the environmental impact of large-scale port and coastal developments.

This project aims to improve understanding of the key physical processes that control the extent, intensity and duration of sediment plumes from both the dredge site and dredge spoil grounds. The rate of deposition and resuspension by waves and currents will vary across habitats and will lead to further dispersal. A combination of satellite and in-situ observations, and numerical modelling, will be used to investigate the sediment transport processes across a range of habitats. Predicted sediment deposition and erosion rates, and bottom light availability will be provided to other themes (Themes 4-6) to predict zones of impact, based on the likely extent, severity, and persistence of dredge plumes generated from the dredging operation. The predicted impacts can then be compared with measured impacts. Predicting zones of impact is an essential component of Environmental Impact Assessment for proposed dredging operations under a spatially defined zoning pattern.

The key management issues addressed by this project are to develop protocols for (i) the incorporation of contemporary understanding, algorithms and parameters in representative numerical models; (ii) the collection of data to optimize plume modelling; (iii) the process of testing and validating model assumptions and predictions. Uncertainty in model predictions can cause delays through the assessment and approvals processes and lead to onerous and costly regulatory regimes. Results from this research will improve the confidence in model predictions and the efficiency and effectiveness of monitoring and managing impacts during dredge operations.

Generation and release of sediments by hydraulic dredging

Des Mills[1,3]

Collaborators: Hans Kemps[2,3]

Institutions: [1]Marine Environmental Reviews, [2]Office of the Environmental Protection Authority, [3] Western Australian Marine Science Institution, Perth, Australia

The scope and some of the findings of a literature review on the generation and release of sediments by trailing suction hopper dredgers and cutter suction dredgers will be presented.

Disintegration and attrition of soil and rock material during the excavation, removal and hydraulic transport stages of dredging operations increases the mass fraction of small particles in the dredged material. Typically, some of this dredged material is released into the marine environment, forming suspended sediment plumes which are transported downstream by ambient currents.

Several different sources of sediment release occur for each dredger type or work method. The distinct mechanisms that are associated with each of these sources influence the mass rates and characteristics of the sediments released. For example, sedimentation and suspended sediment transport within the hopper influences the sediment load in the hopper overflow, which is the largest source of fine sediments released by TSHD dredging operations. This in turn influences the extent and intensity of the dredge plume.

Some dredge plumes have been observed to extend tens of kilometres along the coast. However not all of the sediment released from the dredger necessarily remains in suspension. For example, some particles settle rapidly and are deposited within a localised zone about the dredger (the ‘near-field’), while the balance of the released material remains suspended, clears the near-field, and contributes to the suspended sediment source for the ‘far-field’ dredge plume.

Far-field suspended sediment transport models are used to predict the trajectory, extent and intensity of dredge plumes to support ecological impact prediction for dredging proposals. The input of dredge-induced suspended sediment *source* characteristics to the far-field dredge plume model is key. This requires quantitative estimates of the horizontal mass flux and settling rates of material that feeds into the far-field plume.

Estimating these source characteristics prior to dredging introduces a significant degree of uncertainty for dredge plume prediction and environmental impact assessment, particularly for capital dredging projects at locations where no relevant resuspension data are available.

This literature review has sought to highlight available empirical estimates, process investigations and the development and validation of methods for predicting far-field source terms. It has drawn from field measurement trials during dredging, laboratory tests and numerical simulation models. Recommendations for further work have been made.

Redefining sediment transport models over sensitive benthic habitats

Ryan Lowe[1,3]

Co-author: Marco Ghisalberti[1,3]

Collaborators: Andrew Pomeroy[1,3], Taj Sarker[1,3], Mike Cuttler[1,3], Graham Symonds[2,]

Institutions: [1] UWA, [2] CSIRO, [3] Western Australian Marine Science Institution

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A common feature of many coastal systems is the presence of large and complex bottom roughness (or canopies) on the seafloor that are formed by a wide range of different marine communities, including seagrasses, coral reef organisms and mangroves. These canopies impose substantial drag forces on the coastal flows generated by waves and currents, resulting in substantial modifications to mean and turbulent flow structure adjacent to the seafloor.

As a consequence, the transport of both natural and dredging-derived sediments (which are closely coupled to the hydrodynamics), including rates of sediment deposition and suspension, can be dramatically altered in these environments. Presently, mechanistic models of sediment transport in the presence of submerged canopies are severely lacking, which presently makes it impossible to predict the fate and impact of sediment dredging plumes on these often sensitive environments with any degree of confidence.

In this presentation we will describe a research program that focuses on developing new transport formulations applicable to a broad range of bottom types that characterise benthic ecosystems, thereby building on our conventional understanding of sediment transport over open (bare) sediment beds. For the first part of the presentation, we will describe the first detailed field observations of both the turbulent flow structure and suspended concentrations (via optical and acoustic back scatter sensors, and manual pump sampling) below and above the bottom roughness formed by coral reef communities. These direct measurements of sediment fluxes are compared with various conventional sediment transport formulations and highlight the major deficiencies.

In the second part of the presentation, we will describe parallel controlled laboratory experiments being conducted in a large wave-current flume to accurately quantify the mechanisms by which canopies modify bed shear stresses and sediment transport. Finally, we will detail our future research directions and how these new datasets and theory will be used to improve process-based numerical models used to improve predictions of sediment transport (including the deposition and resuspension of dredge-derived sediments) within these environments.

The light environment in turbid waters

Peter Fearns

Collaborators: Mark Broomhall[1,3], Passang Dorji[1,3], Graham Symonds[1,3,]

Institutions: [1]Curtin University, [2]CSIRO, [3] Western Australian Marine Science Institution

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The most accurate measure of water quality is achieved by direct in-situ sampling. However, this measure is only accurate for the specific time and location of the sample. Collecting samples over a distributed spatial domain can potentially provide improved information of spatial variability. Extended in-situ sampling campaigns are laborious and cost prohibitive. Interpolation of these measurements may provide an indication of spatial patterns, but also can potentially display artefacts and huge uncertainties.

Remote sensing data can provide a complete view of an entire water mass, coastal region, or dredge plume, as well as surrounding waters. The accuracy of the geophysical value represented by each image pixel may defined and included in the interpretation of results. Remote sensing data can be collected by many space-borne and airborne sensors, at various spatial resolutions, spectral resolutions, and temporal resolutions.

Remote sensing of dredge plumes can provide very accurate maps of plume extent, but can also provide estimates of water clarity, and thus light penetration to the substrate. Of particular interest is the total available light at the substrate, and the spectral nature of the light at the substrate. Some environmental monitoring programs aimed at monitoring light levels with respect to their impact on photosynthetic potential only measure "total available energy". This project aims to provide insights into the spectral quality of the light.

We have undertaken two boat-based field campaigns to sample dredge impacted water at Dampier with collaborators from CSIRO and UWA. Water samples were collected to measure total suspended sediment concentration, a surface-mounted radiometer measured surface reflectance, and profiling sensors measured water column light profiles. These measurements will be used to develop improved TSS remote sensing algorithms, as well as to model and study the light field within turbid plumes.

We will present preliminary results of field campaigns. Results will include spectral light profiles, high spatial resolution remote sensing images, and maps of suspended sediment plumes as well as estimates of light at the substrate.

We expect to provide a better understanding of the potential and limitations of remote sensing in monitoring TSS levels, light levels and light quality in turbid waters. Remote sensing products will include pan-sharpened Landsat images and other high resolution data, maps of TSS, and maps of percentage light at the substrate.

Modelling Dredge Generated Sediment Plumes

Graham Symonds

Institutions: CSIRO, Western Australian Marine Science Institution, Perth, Australia

The processes governing the horizontal extent of dredge plumes is examined for two cases, (i) passive plume where the sediment is treated as a scalar and the plume is governed by a depth dependent advection and diffusion equation, and (ii) dynamic plume where the sediment-water mixture is modelled as a two phase flow and the plume is governed by a density driven flow.

In the first case the structure of the plume is governed by the settling time scale, the magnitude of the horizontal advection, and the relative magnitude of advection and diffusion expressed in terms of the Peclet Number, P_e. For $P_e >> 1$ gravitational settling dominates and the plume descends as it is advected away from the source. For $P_e << 1$ turbulence mixes the sediment uniformly through the water column as it is advected away from the source. In the absence of entrainment the mass flux of sediment at the bottom reaches a steady state, and the magnitude of this steady mass flux decreases with distance from the source.

In the second case the sediment concentration is sufficient to increase the density of the sediment-fluid mixture which flows away from the source as a density current. Secondary circulation is established above the plume and some sediment, particularly near the head of the density current, is entrained into the overlying fluid and resettles back into the plume leading to an increase in sediment concentration some distance behind the head. Within the plume the presence of high concentration sediment inhibits turbulent mixing and leads to the development of a sludge layer behind the head of the density current.

Consultant's perspective on WAMSI Dredging Science Node

Invited Speaker

Ian LeProvost (Past president ECAWA)

Collaborators: Mark Bailey, Rob DeRoach (BMT Oceanica), Jim Stoddart (MScience).

Institution: Environmental Consultant's Association of Western Australia (ECA of WA)

The ECA of WA represents environmental professionals who work in the consulting industry. There are approximately 300 members and most of the major consulting firms are corporate members. Some 50 or so members are marine scientists and many have been involved in undertaking environmental impact assessments for major port developments in WA over the past 15 years.

ECA has a Partnering Agreement with the OEPA aimed at improving EIA practice in WA and relations between consultants and regulators. To this end, the association has in recent times undertaken a number of joint learning workshops with the OEPA on a range of topics considered relevant to our membership. One of these workshops (held in September 2011) was focussed on "Lessons Learned from Dredging" and presented a number of case studies of recently completed dredging programmes in WA. The key lesson learned from the workshop was that the application of conservative mortality thresholds in impact assessment was resulting in consistent over-prediction of scale of impacts which resulted in a requirement for complex monitoring programs.

The ECA in 2010 also prepared a 10 page submission to the EPA on the draft EAG 7 for Marine Dredging Proposals seeking clarification of intent and making suggestions for improvement. These suggestions were taken on board by the EPA and the final EAG 7 is now considered by the ECA to be a clear statement of the EPA's expectations of consultants and proponents. Particularly welcome is the acknowledgement by the EPA that there is a high level of uncertainty inherent in dredging impact prediction and that many information gaps exist which make the delivery of reliable assessments difficult. Also welcome is the EPA's recognition of the need to make all proponent monitoring results publically available, and the EPA's support for the WAMSI Dredging Research Initiative.

The ECA has supported the WAMSI Dredging Research Initiative since its inception and various members have contributed information, data, and dredging contacts to the researchers. The ECA has also been represented on the Dredging Science Advisory Council as an observer and been kept informed of developments. We look forward to the outcomes of the research node, particularly if they reduce uncertainty and increase confidence in the reliability of our predictions.

Theme 5: Defining thresholds and indicators of primary producer response to dredging related pressures

Paul Lavery

Collaborators: [1]Paul Lavery, [1]Kathryn McMahon, [1]Roisin McCallum, [1]Simone Strydom, [1]Paul Armstrong, [2]Gary Kendrick, [2]John Statton,, [3]Mat Vanderklift, [3]Mick Haywood, [3]Doug Bearham, [3]James McLoughlin, [3]Hector Lozano-Montes

Institutions: [1]ECU, [2]UWA, [3]CSIRO

Dredging impacts primary producers through mechanisms such as reduced light availability and burial under deposited sediments. This project aims to determine: (i) the ability of seagrasses, an important group of primary producers, to tolerate changes in light availability and sediment burial; (ii) their ability to recover from these stresses; and (iii) the most appropriate indicators to used in seagrass monitoring programs.

Two reviews were undertaken to determine which primary producers to focus research effort on and what was known about their tolerance of dredging-related stresses. Because of their widespread distribution, ecological significance and sensitivity to dredging, the research focuses on three species of seagrasses. Previous research has examined the ability of these species to tolerate light reductions or burial, but never for plants from NW Australia. A review of the effect of dredging on water quality in NW Australia indicated that dredging has the potential to significantly affect seagrasses in the NW. The reviews also identified significant knowledge gaps, including: the distribution, abundance and phenology of seagrasses in NW Australia; the effect of dredging on the conditions they grow under, especially in relation to sediment burial; and the thresholds of tolerance to dredging-related stresses for local species.

Field and laboratory studies have been initiated to address some of these gaps. The field studies have characterised the cover, biomass and phenology of seagrasses at sites in the Pilbara. Further studies are determining the whether seagrasses can recover from dredging-related impacts and the likely timeframe for that recovery. These studies are providing contextual information critical to the assessment of dredging proposals.

The laboratory experiments are being undertaken in a mesocosm facility established as part of this project. Seagrass are being grown under experimental conditions, to determine the tolerance thresholds to light reduction and burial. These experiments will also allow us to determine the appropriate indicators to apply in monitoring programmes.

The outcomes of the project will be applied to the framework for assessing dredging proposals (EAG7). They will inform proponents and regulators on: appropriate methods for pre-development surveys; the likely thresholds of tolerance, to allow impacts prediction; and appropriate indicators for use in pre- and post-dredging monitoring programmes.

Genetic variability, seasonal dynamics and recovery mechanisms of tropical seagrasses – update on field programs in north-west Australia.

Kathryn McMahon

Collaborators: [1]Kathryn McMahon, [1]Paul Lavery, [1]Roisin McCallum, [2]Mat Vanderklift, [2]Mick Haywood, [2]Doug Bearham, [2]James McLoughlin, [2]Hector Lozano-Montes

Institutions: [1]ECU, [2]CSIRO

Dredging impacts primary producers through mechanisms such as reduced light availability and burial under deposited sediments. To be able predict and manage dredging projects we need to understand how habitat such as seagrasses will respond to dredging and recover from it. The ability to tolerate or recover from dredging can vary at different times of the year, depending on the life-cycle and growth of the plants. The field component of the WAMSI Dredging Theme 5 research project aims to fill a number of key information gaps. Firstly, the distribution, abundance, growth and flowering patterns of NW WA seagrasses. Are there consistent patterns in the region? Do these patterns vary with habitat or environmental conditions? Secondly, the recovery mechanisms of seagrass habitat. If seagrass is lost, how does it recover and how long will it take? Here we briefly explain the methodology to answer these two key questions and present preliminary data.

The field study to document the variation in seagrass abundance over time was carried out across three locations, turbid in-shore waters out to clear off-shore islands in the southern Pilbara (Exmouth Gulf to Muiron Islands). Three monthly sampling occurred from August 2013 to February 2015. The temporal patterns in seagrass abundance were not consistent across the locations. In addition there were large variations in abundance of seagrass among locations. Flowering was observed only from November to February.

The field experiment to understand the mechanisms and timescales for recovery, either vegetatively via growth of remaining seagrass plants or via recruitment from seed, is underway at Thevenard Island, in shallow and deeper meadows. Following removal of seagrass there was recovery via vegetative growth within months, but no recovery via sexual reproduction. This experiment is planned to finish in June 2015.

Field sampling and laboratory processing has also been completed to assess the genetic diversity and connectivity of three seagrass species, *Halophila* ovalis, *Halodule uninervis* and *Thalassia hemprichhi* in the Pilbara region. This type of information can inform on the recovery mechanism of seagrasses. For example, over what spatial scale are seagrasses meadows connected, and there over what distance could recruits move and recolonise impacted areas. Preliminary results for *Thalassia hemprichhi,* a seagrass species with floating fruits and the ability to disperse ~ 300 km show connection of populations from Barrow Island to the Muiron Islands. There is directionality in the movement of fruits, movement is more common northwards i.e. from Muiron Is to Barrow Is. than southwards.

Deriving pressure-response relationships of tropical seagrasses to dredge pressures – a laboratory approach

John Statton

Collaborators: [1] John Statton, [1]Gary Kendrick [2]Paul Lavery, [2]Kathryn McMahon, [2]Simone Strydom, [2]Paul Armstrong, [2]Roisin McCallum

Institutions: [1]UWA, [2]ECU

Understanding light stress and sediment burial thresholds and response indicators is critical for robust impact assessment, monitoring and management of dredging activities in tropical marine systems. Currently, knowledge on these thresholds and indicators is limited for NW Australian seagrasses.

In this subproject, we developed a large-scale seagrass research facility at the University of Western Australian to test the effects of light reduction and sediment burial on three co-occurring seagrass species: *Cymodocea serrulata, Halodule uninervis* and *Halophila ovalis.*

In the first experiment, species were exposed to six levels of light reduction; control (100 % surface irradiance, SI), 60, 41, 23, 11, and 4% SI for 12 weeks. All plants in high light (100 and 60% SI) treatments survived and grew over the 12 weeks. The lowest light reduction treatment that caused full mortality was 4% SI and only for *H. ovalis* after 9 weeks. *H. uninervis* and *C. serrulata* were trending to complete mortality at 4 %SI after 12 weeks.

In a second experiment, *C. serrulata* and *H. uninervis* were exposed to five burial depths using fine inorganic sediments, control (0mm), 8, 16, 40 and 70mm. Both species grew vertically, adapting to each sediment height, though *H. uninervis* had a faster growth response (<3 weeks) than C. serrulata (>6 weeks).

In the final experiment for this sub-project, we will test the interactive effect of light reduction and sediment burial on these same seagrass species.

Together, the results from these experimental studies are being used to develop Pressure-Response relationships. These relationships will allow us to determine the lethal and sub-lethal thresholds of light reduction and burial depth for each seagrass species as well as the most appropriate indicators of stress. These outcomes will fill critical information gaps relevant to the prediction of dredging impacts on seagrass and to the ongoing monitoring and management phase of dredging projects.

Theme 6 Overview, Defining thresholds of filter feeder response to dredge pressures

[1, 7] Nicole Webster

Collaborators: [2] Christine Schönberg, [3, 7] Jane Fromont, [3, 7] Oliver Gomez, [1,5] Alan Duckworth, [1, 7] Muhammad Abdul Wahab, [1, 2, 7] Brian Strehlow, [4] Peta Clode, [1] Peter Speare, [5] Merrick Ekins, [5] John Hooper, [6] Evy Büttner E. [6] Flora Siebler , [1, 7] Mari Carmen Pineda.

Institutions: [1] Australian Institute of Marine Science (Perth and Townsville) Australia

[2] The University of Western Australia, Perth, Australia

[3] Western Australian Museum, Perth, Western Australia

[4] Centre of Microscopy, Characterisation and Analysis, The University of Western Australia

[5] Queensland Museum, Brisbane, Queensland, Australia

[6] University of Stuttgart, Baden-Württemberg, Germany

[7] Western Australian Marine Science Institution, Perth, Australia

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Coastal Western Australia (WA) contains dense and diverse communities of filter feeders that are comparatively understudied and are not found anywhere else in the world. These filter feeders occupy coral reefs, dominate the fauna of inter-reef regions as well as being abundant in deep water habitats. They provide immense bio-services including benthic-pelagic coupling, nutrient cycling, purification of vast water masses and provision of 3 dimensional habitat and support for a multitude of other important organisms.

These filter feeding communities are often dominated by sponges, which are difficult to taxonomically classify and which in WA contain many endemic or undescribed species. Extensive dredging projects pose a potential environmental risk to local filter feeder communities through turbidity and light reduction, clogging of filtration systems and smothering of the animals by sedimentation.

WAMSI theme 6 is investigating the nature and thresholds of such risks. The approach being undertaken across the theme includes: i) a review of available literature on sediment effects on sponges to identify key knowledge gaps, ii) a synthesis of sponge biodiversity, biogeography and ecology across northwest Australia to determine the importance of filter feeding communities, iii) field surveys at Chevron's Wheatstone Project to describe local filter feeding communities before and after exposure to dredging pressures, allowing insights into which growth forms, common taxa and feeding strategies are most affected, and iv) controlled aquarium experiments to test pressure:response effects and thresholds of stressor combinations.

The latter component of the research program is further divided into individual experiments designed to tease apart the dredge related pressures of light attenuation, elevated total suspended solids and sedimentation. Within this session we will provide an overview of the identified key knowledge gaps and result from the field and laboratory studies undertaken to date.

Observations from pre-dredging surveys of filter feeders at Onslow, Western Australia

[1] Muhammad Azmi Abdul Wahab

Collaborators: [3]Oliver Gomez, [2]Peter Speare, [5]Evy Büttner, [5]Flora Siebler, [3]Jane Fromont, [4]Christine Schönberg.

Institutions: [1] Australian Institute of Marine Science (Perth) Australia

[2] Australian Institute of Marine Science (Townsville) Australia

[3] Western Australian Museum, Perth, Western Australia

[4] The University of Western Australia

[5] Queensland Museum, Brisbane, Queensland, Australia

[6] University of Stuttgart, Baden-Württemberg, Germany

Coastal Western Australia (WA) supports dense communities of diverse filter feeders that are understudied and globally unique. Assessments of the abundance, diversity and health of filter feeders were conducted at the Chevron "Wheatstone" Project near Onslow, NW Australia, in March 2013 prior to the commencement of dredging activities. Using a combination of large-scale towed video surveys, still photography and small scale transect surveys using SCUBA, we found that filter feeder communities were the dominant benthos, with sponges representing up to 70 % of these communities. Other minority benthic taxa represented in these surveys were cnidarians (represented by gorgonians), ascidians and bryozoans. Initial signs of stress were detected in these communities and were associated to occurrence of a strong thermal event prior to the commencement of dredging.

Extensive proposed dredging projects pose an additional environmental risk to local filter feeder communities through turbidity and light attenuation, impediments to filtering activity and smothering by sedimentation. A post dredging survey scheduled for July 2015, will provide insights into which growth forms, common taxa and feeding strategies are most affected, thus informing, but also in part validating, simultaneous aquarium experiments. Through fieldwork in addition to laboratory experiments we will provide critical insights into local filter feeder communities and their responses to dredging pressures. Identifying relative impacts of different types of stress in combination with thresholds and guidelines will assist stakeholders and managers alike in reducing risks and consequences from dredging operations.

Identifying, characterising and quantifying the effects of dredging on sponges (Porifera)

Brian Strehlow[1,2,3,4]

Collaborators: Peta Clode[3,4], Alan Duckworth[1,4], Gary Kendrick[3,4], Mari Carmen Pineda[1,4], Michael Renton[3], Nicole Webster[1,4]

Institutions: [1]Australian Institute of Marine Science, Townsville, and Perth,

[2]The University of Western Australia Centre for Microscopy Characterisation and Analysis

[3] The University of Western Australia Oceans Institute and School of Plant Biology

[4]Western Australian Marine Science Institution

Sponges are sessile, filter-feeding animals and although they are considered structurally "simple," sponges have surprisingly complex physiologies. As such, quantifying stress from dredge-related pressures necessitates novel methods. We are developing and optimizing three methodologies for detecting and quantifying stress responses. These methods comprise: 1) micro computed tomography (mCT) scanning to visualize sediment management strategies; 2) thermistor flowmeters to measure changes in sponge pumping (i.e. filtering) rates; and 3) RNA-sequencing (RNA-seq) to determine how dredging-related pressures affect host gene expression patterns.

Preliminary analysis with the mCT scanner at the UWA Centre for Microscopy, Characterisation and Analysis indicates that sponges employ both active and passive mechanisms to move sediment within their tissues, accumulating particles in discrete areas. The mCT scanner has the potential to resolve transport mechanisms, and we are currently working on tracing sediment movements through time. The energetic costs of these processes will then be determined and used to evaluate potential stress responses.

The thermistor flowmeter has been developed and built at AIMS Townsville. The flowmeter heats up to ten degrees above ambient temperature and measures the current applied to maintain that temperature when placed in a moving fluid. Higher flows dissipate heat faster, and thus heat "loss" is used as a proxy for water flow. The latest model can measure flows as low as five millimetres per second from openings as small as 1.5 mm. Preliminary experiments indicate that sponges can change their pumping patterns when exposed to short term elevated suspended solid levels and sedimentation. Pumping facilitates respiration, food capture, and waste elimination. Further investigation is needed to determine possible effects of chronic exposure.

Future experiments will employ RNA-seq. Changes in gene expression are expected to govern active sediment aggregation as well as altered pumping patterns. Furthermore, gene expression patterns may indicate potential acclimatization to different pressures. These studies will increase our knowledge of sponge biology, and more importantly, elucidate potential cause-effect pathways and dose-response relationships associated with dredge-related pressures.

Deriving pressure-response relationships of sponges to dredge pressures – a laboratory approach

Mari-Carmen Pineda[1,2]

Collaborators: Nicole Webster[1,2], Alan Duckworth[1,2], Brian Strehlow[1,2]

Institutions: [1]Australian Institute of Marine Science, [2]Western Australian Marine Science Institution

Dredging activity poses an environmental risk to filter feeders as sediments may smother the animal surface, clog the aquiferous system or reduce light penetration required for photosynthesising symbionts. Sponges are a dominant component of epibenthic fauna in northern Western Australia hence the aim of WAMSI Dredging Science Node theme 6.4 is to test pressure: response relationships and determine thresholds for sponges and their symbionts.

To achieve this, we are performing five large scale experiments, at the National Sea Simulator (AIMS) to study the effects of dredging-related pressures in a selection of representative sponge species, comprising different morphologies and nutritional strategies (phototrophs vs. heterotrophs). These cause/effect experiments will tease apart the effects of light reduction, elevated suspended solids and sedimentation associated with dredging activity.

High sedimentation rates (Experiment 1) were found to partially affect massive, encrusting and cup sponge morphologies. Dredging-related light attenuation (Experiment 2) did not cause any visible effect on the heterotrophic sponge species but resulted in bleaching of most phototrophic species. Differential scope for recovery was observed amongst the phototrophic species. The bioeroding sponge *Cliona orientalis* was able to recover fully after 2 weeks in natural light whereas the cup sponge *Carteriospongia foliascens* did not regain its native photosymbiont status, and died during the recovery period. High total suspended solids (Experiment 3) caused regression in most sponge species, although it only caused necrosis and mortality within the cup sponge *C. foliascens* and the massive sponge *Coscinoderma matthewsi*.

In conclusion, sponges seem largely tolerant of short term (< 4 weeks) dredging-related pressures; however these tolerance limits are species-specific with wide cup and massive morphologies being the most sensitive and bioeroding sponges being the most resilient. In summary, we are defining sub-lethal stress and mortality thresholds in ecologically important filter feeding species to assist regulators and environmental managers in reducing risks from dredging development.

Industry perspective on WAMSI Dredging Science Node

Invited Speaker

Luke Smith

Woodside Energy

Woodside believes that robust science needs to underpin our environmental risk management processes. The lack of good science or knowledge can lead to high degrees of uncertainty. This uncertainty can lead to:

- over-estimating our environmental impacts;
- cause heightened environmental concerns from regulators or key stakeholders that are potentially unwarranted;
- increased need for complex and expensive compliance monitoring programs; and
- potentially cause regulatory approval delays.

This presentation looks at the importance of robust science in a dredging context and the challenges for the WAMSI Dredging Science Node from an industry point of view.

Theme 4 Overview: Dredging and Corals

Ross Jones[1,6]

Collaborators: Rebecca Fisher[1,6], Pia Bessell-Browne[1, 2, 6,] Alan Duckworth[1, 6,] Natalie Giofre[1, 6], Wojciech Klonowski[4, 5,] Matthew Slivkoff[4, 5,] Clair Stark[3, 6], James Whinney[3, 6], Peter Ridd[3, 6]

Institutions:
[1] Australian Institute of Marine Science (Perth and Townsville) Australia

[2] Centre of Microscopy, Characterisation and Analysis, The University of Western Australia, Perth, Western Australia, 6009, Australia

[3] School of Engineering and Physical Sciences, James Cook University, Townsville

[4] Curtin University, Bentley, Perth, Australia

[5] In situ Marine Optics, Bibra Lake, Perth, Australia

[6] Western Australian Marine Science Institution, Perth, Australia

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There is a critical need to better predict and manage the effects of dredging near sensitive environments such as coral reefs. One approach is to develop water quality thresholds that define exposure conditions above which effects could occur. Use of these thresholds could reduce the need for costly biological surveys/compliance monitoring in future projects and developing thresholds is the primary focus of Theme 4.

As part of the research planning process a detailed review was conducted of the effects of sediments on corals. Although there have been many published studies it became apparent that there is surprisingly little available information on the water quality conditions that can occur during dredging programs making it difficult to place the results of past studies into any real context. There was also found to be little reliable information, or even approaches, to evaluating one of the key pressures, sediment deposition.

Theme 4 therefore started with a detailed investigation of spatial and temporal characteristics of water quality using data from several dredging programs in the Pilbara in recent years, examining sediment particle sizes, suspended sediment concentrations and changes in light quantity and quality. Projects were initiated involving a modelling approach to estimating deposition and the development of submersible *in situ* deposition sensors.

Using information from these projects sediment dosing systems were developed at the National Sea Simulator at AIMS to examine effects of sediments on corals using environmentally realistic, relevant exposure conditions. A series of experiments have now started using common and widely-distributed (throughout the Indo-Pacific) coral species. Coupled to these experiments, which are primarily focussed on cause-effect pathways, are detailed study of the WQ conditions and fate of tagged corals during some of the Pilbara dredging projects.

The review and preliminary results from these studies and will be discussed in the session.

Specific and interactive effects of total suspended solids, light attenuation and sediment deposition on adult corals

Alan Duckworth[1,2]

Collaborators: Pia Bessell-Browne[1,2,3], Natalie Giofre[1,2], Ross Jones[1,2]

Institutions: [1]Australian Institute of Marine Science, Townsville, 4180, Queensland, and Perth

[2]Western Australian Marine Science Institution

[3]Centre of Microscopy, Characterisation and Analysis, The University of Western Australia

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Increased concentrations of total suspended solids (TSS), and subsequent light attenuation and sediment deposition are the three primary cause – effect pathways whereby sediments released into the water column by dredging activities could reduce the health of adult corals. These may act alone or in combination making it challenging to generate pressure – response relationships.

Over the last few years we have been developing two sediment dosing systems at the National Sea Simulator at AIMS. With this national facility, we can maintain sediments in suspension at stable levels, manipulate light quantity, and allow sediments to drop out of suspension and be resuspended, simulating sediment deposition and resuspension events. The tanks are continually turned over with fresh seawater (and sediment) and all parameters (light, TSS, sedimentation rates, temperatures) are automated, tightly-controlled and logged on a supervisory control and data acquisition (SCADA) system. Using the dosing systems, combined with water quality information from recent large scale capital dredging programs in the Pilbara, we have begun a series of experiments into cause-effect pathways of different coral species and morphologies.

Some preliminary results are presented from several experiments, including an examination of the specific and interactive effects of high TSS and reduced light which suggests that TSS alone does not negatively affect corals as opposed to the associated effect of light attenuation. Sediment clearing abilities of different colony morphologies exposed to different particle size distributions and flow regimes are also shown, indicating marked differences in sedimentation tolerance. Subsequent experiments will be examining the survivorship of different species and morphologies to sediment smothering.

Turning data into management recommendations: Predicting coral deaths based on water quality during dredging

Rebecca Fisher[1,]

Collaborators: Ross Jones[1,4,] Pia Bessel-Brown[1,2,4,] Clair Stark[3, 4,] Peter Ridd[3, 4]

Institutions: [1]Australian Institute of Marine Science (Perth and Townsville) Australia

[2]The University of Western Australia, Perth, Australia

[3]School of Engineering and Physical Sciences, James Cook University, Townsville

[4]Western Australian Marine Science Institution, Perth, Australia

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Over the last decade there has been a series of large scale dredging programs off Australia's North West Coast. These projects were large by global standards, in terms of the dredge volumes processed as well as the scale and quantity of associated water quality and biological data that were collected. The data collected during these programs provides an excellent opportunity to explore: what happens to water quality during dredging; how this impacts upon coral health; the spatial and temporal scale of dredging impacts; and may ultimately allow the development of water quality threshold values that can be used to manage other dredging programs in the future.

Characterising water quality using turbidity and light data collected over minute time frames yet spanning time series of several years can be highly complex, and can differ greatly across temporal scales (hours versus month) and with the statistical metrics used (mean verus median). A myriad of derived metrics are possible, and these must be compared with respect to anticipated pressure fields associated with dredging, the biology and ecological characteristics of the exposed communities, and ultimately in terms of their capacity to predict resulting coral mortality. Once we fully understand what causes mortality of benthic communities during dredging, management recommendations and practical applied water quality thresholds for managing future dredging programs can be derived.

Measuring sediment deposition during dredging programs: development of an in situ deposition sensor

James Whinney [1,3,]

Collaborators: Ross Jones[2, 3], Alan Duckworth[2,3,] Peter Ridd[1, 3]

Institutions: [1]School of Engineering and Physical Sciences, James Cook University, Townsville,
[2] Australian Institute of Marine Science (Perth and Townsville) Australia
[3] Western Australian Marine Science Institution, Perth, Australia

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Dredging can lead to an increase in sediment suspended in the water column. This can harm marine organisms by reducing the available light and increasing the amount of sediment that is deposited on them, forcing them to expend energy to remove it or risk smothering.

The suspended sediment can be measured using nephelometers and the attenuation of light can be measured with PAR light sensors. It is however more difficult to measure the deposition of sediment. The most common technique to measure deposition is to use a sediment trap, but this can only take one reading per deployment and as it does not allow for resuspension and is more likely to measure gross deposition.

The deposition sensor developed in this project uses optical back scatter allowing readings to be taken every few minutes and uses a perforated plate on top of the sensors to mimic the surface of a coral so that deposition occurring on the instrument is similar to that on a coral. During the development of this sensor it has been tested at AIMS, used in experiments at SEASIM and also deployed in Cleveland Bay, Townsville, Queensland and on the site of the Wheatstone Project, Western Australia. The data from the sensor is promising, measuring expected levels of sedimentation in the laboratory and gathering interesting data from the field which compares well with wave and turbidity data.

Measuring sediment deposition during dredging programs: modelling approaches

Clair Stark[1,3]

Collaborators: Peter Ridd[1, 3] James Whinney[1, 3] Ross Jones[2, 3]

Institutions: [1]School of Engineering and Physical Sciences, James Cook University, Townsville,
[2] Australian Institute of Marine Science (Perth and Townsville) Australia
[3] Western Australian Marine Science Institution, Perth, Australia

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Sediments released into the water column by dredging (or dredge spoil disposal) can significantly impact sensitive marine communities (i.e. coral reefs or seagrass beds) by reducing or blocking light, by clogging filtering/feeding processes and especially by smothering organisms. While marine communities are naturally adapted to occasional periods of elevated suspended sediment concentrations (SSCs), high levels in dredging plumes could exceed physiological tolerance levels, especially as the high turbidity levels are likely to be associated with periods of high sediment deposition.

Being able to distinguish between high SSC concentrations caused by natural processes or by dredging is very important for effective management of dredging operations. There are many coupled sediment transport and hydrodynamic models that can predict SSC levels and sediment transport rates. However, these are computationally demanding and usually require the collection of multiple input variables which is difficult and costly to acquire.

Here we present a very simple site-specific SSC model based on measurements of turbidity and water pressure. The model variables include the primary natural resuspension processes (i.e. wave height, water depth and tidal currents) and model parameters are determined using baseline data (collected prior to dredging) by fitting the model variables to *in situ* SSC measurements. When used during a dredging program, the model will predict the SSC levels and any differences between the predicted and the observed, in situ, SSC levels will be caused by sediments resuspended by dredging.

Comparing *in situ* SSC measurements to model values will therefore enable dredge operation managers to perform real time monitoring of dredging impacts on sediment conditions, identify dredging plumes and potentially allow calculation of indices of cumulative stress. The application of the model to a real dredging program close to a sensitive environment (the Chevron 'Gorgon' Dredging Program at Barrow Island in WA) is demonstrated.

Theme 7 Overview: Effects of dredging on coral reproduction

Andrew P. Negri[1,2]

Collaborators: Ross J. Jones[1,2], Gerard F. Ricardo[1,2,3], Peta L. Clode[2]

Institutions: [1]Australian Institute of Marine Science, Townsville and Perth,
[2]Western Australian Marine Science Institution,
[3]Centre of Microscopy, Characterisation and Analysis, UWA

Sediments generated during dredging can affect many aspects of coral reproduction and recruitment processes which underlie the maintenance of communities and their resilience to disturbance. This potential risk is recognised by regulators and the "Environmental Window" shutdown (EW) of dredging operations during multi-specific synchronous coral spawning events is often required for developments in close proximity to coral communities. This precautionary approach affords some protection for coral communities; however, the precise application, timing, duration and effectiveness of EWs need further refinement.

Theme 7 of the WAMSI Dredging Science Node addresses the environmental effects of sediments on the early life-history stages of corals, coral spawning EWs and shutdown procedures as applied to large scale dredging projects in WA.

This overview of Theme 7 describes the outcomes of a critical review on our current understanding of the effects of sediments on coral reproduction. A conceptual model was developed to identify known and biologically plausible cause–effect pathways whereby turbidity and sediment deposition could affect the reproductive cycle of corals. The review emphasizes: (i) the close interlinking of proximate factors which could confound the interpretation of studies, (ii) the need to identify the specific mechanism of effects, and (iii) the requirement to accurately quantify exposure conditions hence dose-response relationships. New experimentally-tested cause-effect pathways, including gamete ballasting and embryo cloaking will be discussed and dose-response thresholds for sediment impacts on coral fertilisation and larval survival presented.

Coral reproduction in Western Australia

James Gilmour[1]

Collaborators: Conrad Speed[1], Russ Babcock[2]

Institutions: [1]Australian Institute of Marine Science, [2]CSIRO

Sexual reproduction in corals involves the broadcast spawning or brooding of gametes. The spawning of gametes can be highly synchronised among species and colonies (mass spawning) or may be protracted over many nights and several months, while the release of planulae by brooding corals tends to occur over several months of the year. Spawning and brooding modes of sexual reproduction underpin the maintenance of most coral communities, but regardless of mode of reproduction, the associated life history stages can be particularly susceptible to changes in water quality arising from human activities. Managing these human activities therefore requires knowledge of the times of coral spawning and planulae release.

Most studies of coral reproduction in Western Australia have been conducted during just a few months at several reefs, usually within the Kimberley oceanic region, the inshore Pilbara or at Ningaloo Reef, leaving large spatial and temporal gaps in knowledge. Nevertheless, there are consistent differences in spawning activity at most reefs among seasons, with mass spawning during autumn occurring on all reefs (but the temperate southwest), and participation in a second multi-specific spawning during spring decreasing from roughly 25% of corals on the Kimberley oceanic reefs to little or no multi-specific spawning in spring at Ningaloo. Within these seasons, spawning occurs most commonly in March and in October, but can occur during the following month or be split over the two consecutive months, depending on the timing of the full moon. Although fewer data exist for brooding corals, larval release seems to occur during most months from spring to autumn across most regions of WA.

Beyond these general patterns, our current knowledge of coral reproduction is limited by the available data and in some instances the way data have been collected, while inferences about the significance of periods of reproduction are hampered by the lack of a quantitative means of assessment. We briefly discuss some methodological issues related to determining spawning periods and also present an approach to quantifying the significance of reproductive output on reefs as an initial step towards developing standardized approaches.

Coral settlement patterns on sediment-laden surfaces

Gerard F. Ricardo[1,2,3]

Collaborators: Ross J. Jones[2,3], Peta L. Clode[1,3], Mikaela Nordborg, Andrew P. Negri[2,3]

Institutions: [1]Centre of Microscopy, Characterisation and Analysis, UWA
[2]Australian Institute of Marine Science, Townsville and Perth
[3]Western Australian Marine Science Institution, Australia

Sediment deposited on marine surfaces is known to inhibit coral settlement but threshold values have not been adequately quantified nor are the underlying mechanisms well understood. Here, we use dose - response experiments to measure inhibition rates under various deposited sediment regimes (0 – 300 mg cm^{-2}) including two particle size classes (<32 µm and 32-53 µm) and two sediment composition types (lateritic-terrigenous and carbonate).

Settlement was greatly inhibited at low deposited sediment levels regardless of sediment type or particle size, with IC_{10} values (10% inhibition of settlement) at ~0.5 - 4 mg cm^{-2}. When larvae were presented with a suite of surfaces covered in various thickness of sediment films, settlement was inhibited at 0.55 mg cm^{-2}. Finally, temporary sediment deposition (5 mg cm^{-2} for 6 days) on natural settlement inducer surfaces caused 75% surface bleaching of crustose coralline algae and reduced subsequent settlement of larvae, even when the sediments had been removed.

These threshold values indicate that even a thin film of sediment can have adverse consequences for larval settlement.

Dredging in the Pilbara – A Ports' Perspective

Invited Speaker

Wayne Young

Pilbara Ports Authority

Collaborators: Dan Pedersen, Brad Kitchen

Pilbara Ports Authority manages the current ports of Port of Ashburton, Port of Dampier and the Port of Port Hedland. This spans some 470km of the West Australia coastline and includes some of the largest export Ports in Australia, seeing some 10,000 ship visits across the combined ports per year.

In recent years, this area has seen unprecedented growth, including large scale capital project development. From 2010, some $100B of capital investment has been undertaken in these Ports alone, and included more than 30 million cubic metres of development dredging.

The Pilbara Ports Authority has a statutory responsibility to facilitate trade, ensure the safety of the Ports as well as protect the environment of the ports from the impacts of development – potentially conflicting obligations.

This presentation outlines the scope and scale of the Pilbara Ports Authority's responsibilities, how dredging projects are forecast, approved, executed and managed within PPA's waters and how the data collection, collation and synthesis by the Dredging Science Node facilitates this management. The future direction of the Authority is also discussed with horizon projects and our management framework.

Theme 8: Effects of dredging-related pressures on critical ecological processes for finfish

Euan Harvey

Collaborators: Euan Harvey, Ben Saunders, Chris Rawson, Nicola Browne, Jean-Paul Hobbs, Jennifer Mclwain (Curtin), Amelia Wenger (JCU), Stephen Newman, Mike Travers (DoFWA), Shaun Wilson, Rich Evans (DPaW), Dianne McLean (UWA), Doug Clarke (USA), Paul Erftemeijer (Jacobs/SKM), Martial Depczynski (AIMS)

Institutions: Curtin, JCU, DoFWA, DPaW, UWA, AIMS, Jacobs/SKM

Dredging can have significant impacts on marine environments, but its effects on fisheries are still largely unresolved. One strategy that has been used to minimise the impacts of dredging on corals is to cease or limit dredging activity during sensitive life history periods (e.g. reproductive periods), which are most vulnerable to the mechanisms of dredging.

A workshop in 2013 provided the focus for a literature review which assessed the effects of dredging on different life stages of marine fishes from around the world, to determine if a similar strategy could be employed for fish. This review identified a suite of traits which make fishes vulnerable to dredging. Mobile fishes can modify their behaviour and actively avoid areas of dredging. Increases in suspended sediments (SS) can affect processes requiring vision such foraging, hunting and predator avoidance. Increases in SS can have physiological impacts such as gill impairment causing decreases in respiration and increases in diseases. It can also impact chemoreception and the ability of larval recruits to detect suitable habitats for settlement. Benthic eggs and larvae can be smothered, producing negative impacts on survival and growth of recruits. Pelagic eggs can be impacted by sediment adhesion resulting in the eggs sinking. Hydraulic entrainment of fishes at various life stages and their food sources is a localised concern as is the marine noise associated with dredging. Most of the effects of dredging are limited to a spatial scale of kms rather than 10s or 100s of kms, although there are examples of the impacts of dredging covering substantially larger areas. As a consequence the impacts of dredging are of concern to recreational and commercial fisheries, traditional owners and resource managers.

Data were collated from the peer reviewed literature, grey literature and expert opinion on the above identified characteristics of a broad range of temperate and tropical Western Australian marine fishes that are of commercial, recreational or cultural significance. From this information we have developed a priority assessment process that can be used to identify individual species which may be of concern to dredging activities. This process has assisted in identifying gaps in current knowledge in Western Australia. Large gaps in local knowledge exist, particularly with respect to the timing of key ecological processes for major species of marine fishes. We recommend further targeted research for high priority species of fish that may be vulnerable to dredging in order to assess the ecological impacts and thus contribute to better informed management.

Theme 9: Effects of dredging-related pressures on critical ecological processes for other organisms (including potential to facilitate the establishment of invasive species).

Gary Kendrick

Collaborators: Gary Kendrick, Dianne McLean, Jessie Short, John Statton and Sam Gustin-Craig (UWA), Paul Lavery and Kathryn McMahon (ECU), John Keesing (CSIRO), Julian Caley and Ross Jones (AIMS), John Huisman (Murdoch University), Ray Masini (OEPA), (Stuart Field (DPaW), Doug Clarke (USA), Mick Keough (University of Melbourne), Paul Erftemeijer (Oceans Institute, UWA), Maria Byrne (Univ. Sydney), Michael Rasheed (James Cook University), Jim Stoddart (MSCIENCE), Paul Wu (QUT), Kerrie Mengersen (QUT) and Andy Davis (UOW), Ash Lemmon (Jacobs).

Institutions: UWA, ECU, Murdoch, CSIRO, AIMS, OEPA, DPaW, UMelbourne, USydney, JCU, MScience, QUT, UoWoolongong, Jacobs

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Dredging has significant impacts on benthic marine organisms through mechanisms such as sedimentation, burial and reductions in light through increases in turbidity. Marine benthic organisms are particularly vulnerable to dredging. One strategy to minimise impacts of dredging on benthic organisms is to cease or limit dredging activity during sensitive life history periods (e.g. reproductive periods), which are most vulnerable to the mechanisms of dredging.

Two national workshops (2013, 2014) were held in Perth and gathered expert knowledge to 1) identify critical ecological processes and their timing for temperate and tropical marine benthic organisms; and 2) investigate the potential for establishing ‘environmental windows’ when dredging activities could proceed with limited impacts on these non-coral and non-fish biota. Given the likely location-specific responses to dredging impacts, we investigated the timing of potential environmental windows in Western Australia and discussed how these may be applicable elsewhere. Large gaps in knowledge exist, particularly with respect to the timing of key ecological processes for major species of marine invertebrates, seagrasses and macroalgae. We recommend further targeted research especially to inform the management of ecological impacts to dominant sessile benthos and in influencing invasive species colonisation of modified benthic habitats.

An adaptive management framework was explored which will allow refinement of environmental windows as new information becomes available. There is a positive relationship between the amount of information incorporated into this framework and both the accuracy of the risk assessment and the flexibility it will provide managers. We warn that dredging management based on environmental windows for single groups of organisms (e.g. a single taxon) may increase the impact and cost of the dredging operation. A more useful approach is risk based, wherein individual dredging programs are assessed based on known risks to benthos at a particular location.

The Kimberley Marine Research Program. An Overview

Stuart Field

Collaborators: Kelly Waples

Institutions: Department of Parks and Wildlife

The Kimberley Marine Research Program (KMRP) has been commissioned by the State Government to provide a baseline of information for marine park management, and future coastal planning. The program will deliver the first regional scale baseline of marine environmental information in the Kimberley. While the program will provide a step change improvement in information for management, it will necessarily be at a foundational level of understanding.

The WA State Government committed the KMRP funding through The Western Australian Marine Science Institution (WAMSI) to support the planning and management of the proposed State marine park network across the Kimberley. The resulting research program, coordinated by the Department of Parks and Wildlife, includes 25 research projects led by the WAMSI partners taking place across the Kimberley.

This regional view of the marine environment and identified values in the Kimberley will enable a better assessment and management of the impacts and risks to these values. The program is focussed on two main areas of research:

- Describing the biological, physical and social environment including the marine values and the current pressures upon them; and
- Understanding ecosystems including how they function and respond to human pressures and climate change

The 25 projects cover a range of topics including habitat mapping, biology, marine animal abundance and distribution, connectivity, oceanography, geomorphology, water quality, nutrient flow as well as, social values, human use and climate change impacts. Indigenous involvement is a key component to the success of the KMRP and, while there are 2 projects specific to this (Traditional knowledge and Social values), all projects will seek to engage with Indigenous people to include their participation and to ensure the outcomes of the research benefit local communities.

The program has been designed to build an overall picture of the Kimberley and this important marine environment by gathering information that will support the long term understanding and management of this area. To achieve planned outcomes, the complex research methodologies have been focussed on delivering information that support the Program objectives (integration), and science findings must be provided in a form that is useable and useful for managers (knowledge uptake).

The Kimberley Environment

Invited Speaker

Barry Wilson

Marine biologist

A dominant feature of the modern Kimberley coastal marine environment is the abrupt change of geology at Cape Leveque from Palaeozoic igneous and meta-sedimentary in the north (Kimberley Bioregion) to Mesozoic sedimentary in the south (Canning Bioregion). The coastal bathymetry of the north is essentially a rough terrestrial landscape flooded by the Holocene transgression, while that of the south is gently sloping. Superimposed over these grossly different habitats are the effects of Quaternary eustatic history and north to south transitions in climate (wet tropics to arid) and tidal range (moderate to extreme). Put together, these factors define the modern marine environment of the Kimberley and their history provides essential background for ecological and biogeographic science in the region and predictions about impacts of further change.

The Kimberley marine science program can be seen as a search for explanations about how the modern environment came to be the way it is. Science is not the only way people do this. Explanations based on the creative efforts of spirit folk served the indigenous people of Kimberley well. We are now seeing a transition from creation stories of that kind to a science approach. People will put together elements of both to satisfy current cultural and economic needs as they see them. It is important that this process is respected.

In the Kimberley, the science approach began almost 200 years ago when the British Admiralty initiated a series of hydrographic surveys of the region. The first of these was the survey by King on the *Mermaid* and later the *Bathurst* (1820-22). Then came Wickham and Stokes aboard the *Beagle* (1837- 44). And finally the *Penguin* (1890-91) an expedition about which we know very little. All these surveys produced information about the regional natural environment but it was fragmentary. Little more was discovered about it until now. Nevertheless, we may see our present research in a context of ongoing effort to establish a Kimberley story. But we are not the first.

Coral Reef Geomorphology

Lindsay Collins

Collaborators: Dr Mick O'Leary, Alexandra Stevens, Giada Bufarale, Moataz Kordi, Tubagus Solihuddin

Institution: Curtin University

The first Kimberley study of reef geomorphology is drawing to a successful conclusion.

There were 3 primary objectives: 1) To use remote sensing (RS) to map the major reef platforms, both their geomorphology, and substrate / sediment distribution, and provide a geodatabase of key reefs; 2) To seismically determine reef architecture and growth history considering past sea level (SL) events; and 3) To determine the Holocene growth history of the reef system.

The RS study developed a geomorphic classification scheme for the Kimberley reefs, using Geographic Information Software (GIS); mapped the geomorphology, habitats and substrates for 30 of the large reef platforms; and recorded more than 800 reefs, which were classified according to the scheme developed for the Kimberley Bioregion. The end product was the construction of a geodatabase (ReefKIM) which will provide scientists and others (Marine Park Managers, TOs) with quality information relevant to the monitoring, conservation and management of the Kimberley reefs.

In the first high resolution 2D and 3D seismic study, about 300 km of seismic profiles revealed the internal structure of several reef platforms, for fringing reefs of different types, fringing, platform reefs and shoals. Results showed the interaction of SL, subsidence, and pre-existing topography in reef growth; established Holocene and Pleistocene reef growth events, and established a preliminary reef classification scheme. Most inner shelf reefs consisted of 2 stages of reef growth (Holocene and Last Interglacial), overlying metasedimentary and metamorphic basement as initial substrates for reef growth; whereas mid-shelf reef platforms (e.g. Adele reef) exhibited at least 3 growth stages. The Holocene and Last Interglacial reefs were correlated with dated reefs from Cockatoo Island. The Adele Group of offshore reefs are separated by deep (>100 m) incised valleys, cut into the shelf during low stands of the sea, whereas reef growth was confined to intervening high stands, a pattern which conforms to the global sea level curve.

Mine pit mapping on Cockatoo Island, where an entire Holocene reef was exposed, determined that there was ~13 m of vertical reef growth in 8,900 ^{14}C y. Thus the full stratigraphy of at least one Holocene reef was established, allowing contrasts to be made with Holocene reefs of the GBR, where comparable muddy reefs exist. Though the Cockatoo Reef is a catch up reef, the sea level data obtained allowed comparisons to be made between the macrotidal high subsidence reefs of the Kimberley and the microtidal, low subsidence reefs of SW Australia, and the muddy reefs of the inner GBR.

A program of dating and analysing 6 m cores of several reefs is providing detailed information on growth, over the last 5 ky, of the inshore muddy Kimberley reefs.

Benthic biodiversity along the Kimberley coast

Andrew Heyward

Collaborators Jane Fromont, John Keesing, Ian Parnum and team members
Institutions: AIMS, WA Museum, CSIRO, Curtin University

Novel and rich species diversity, complex spatial patterns and limited pre-existing data on the processes responsible have been hallmarks of marine ecosystem studies in the northwest. There is good reason to expect this tradition of initial exploration and subsequent discovery will continue during this project's study of seabed biodiversity along the Kimberley coast. It is a collaboration between AIMS, the WA Museum, CSIRO and Curtin University.

This project seeks to allow comparison of the habitats and benthic species distributions based on surveys in the southern, central and far northern sections of the ria coast and make a substantial contribution to the Kimberley marine reference collection of biota at the WA Museum. Survey locations will be selected to simultaneously inform MPA development in the Kimberley near shore environments, beginning with work in the Lalang-garram-Camden Sound Marine Reserve . Ship-based field expeditions between Camden Sound and the general Cape Londonderry region, including offshore northern waters related to turtle habitats, will use towed camera benthic transects, a range of hydro acoustic and optical remote sensing methods and epibenthic sled collections. To complement the ship-based surveys, the scientists will also work with Indigenous groups of the Kimberley coasts, including the sea rangers, to gather additional information about shallow, near-shore areas more readily accessible from smaller boats.

November 2014 saw the commencement of fieldwork, with a cooperative effort by scientists and staff on board AIMS' RV Solander and CSIRO's RV Linnaeus. Both vessels used multibeam to map the seafloor topography, towed cameras to characterise the habitats, and sampled sediments across the broad area of the Marine Reserve. They successfully completed more than 200 km of towed video from approximately 150 locations and thousands of kilometres of multibeam seafloor mapping,. The towed cameras revealed large areas of dynamic sand across the open Sound, including some patches with underwater sand dunes, but also more localised areas of rocky ground covered in a large variety of marine invertebrates, in particular sponges and soft corals. The turbid waters appear to restrict organisms that need light, such as hard corals and seaweeds, to the shallowest rocky ground and the upper edges of fringing reefs around islands. As depth increases beyond around 10m and light fades, the filter feeding sponges, soft corals, ascidians and bryozoans become the dominant components of the seabed communities. High resolution photos revealed in addition to habitats where larger sponges and other filter feeders were apparent during video tows, very diverse life was often present on submerged rocks and ledges, but many of the organisms were small or encrusting. A second expedition to the Camden Sound area, supporting further habitat surveys and collection of representative taxonomic specimens is in progress during March 2015.

Physical oceanographic dynamics in the Kimberley

Greg Ivey

Collaborators Richard Brinkman (AIMS), Ryan Lowe (UWA), Nicole Jones (UWA), Alexis Espinosa (UWA)
Institutions: Australian Institute for Marine Science (AIMS), University of Western Australia (UWA)

The research in this project has involved both field and numerical modelling work and the talk will summarise the findings to date.

Results will be described from two major field components: 1) the deployment and long-term maintenance of three oceanographic moorings at the inner, mid and outer shelf regions and 2) two ten-day process-oriented research cruises on the RV Solander, one in the dry season and one in the wet season. Both of these field components were undertaken in the Camden Sound/Collier Bay region. Analysis of Collier Bay measurements is examining the tidal constituents and their spatial variation at the various sites, the seasonal variability in the flow structure and the residual flows in this macro-tidal environment.

In the numerical modelling component, a ROMS-based hydrodynamic model for the Camden Sound/Collier Bay region has been set-up. The model is tidally forced at the offshore boundary, freshwater input from Walcott Inlet can be incorporated, and model grid scale varies from 800 m offshore to 500 m close to the coast. Initial and boundary conditions are determined from HYCOM climatology and wind and surface heat forcing applied at the free surface. The model is currently being developed and tested against the field observations, and being used to determine residual flows and the cross-shelf exchange of water masses.

Pathways to Production: Biogeochemistry off the Kimberley Coast

Matthew Hipsey

Collaborators: Miles Furnas, Jim Greenwood, Allison McInnes, Louise Bruce, Thomas Nguyen, David McKinnon, Anya Waite, Nicole Patten, Nicole Jones

Institutions: The University of Western Australia, CSIRO, AIMS

Compared to other regions of Australia, Kimberley coastal waters are largely pristine, but little studied. The Kimberley coastal ecosystem supports a rich diversity of fauna and flora; however, the pathways by which regional primary and secondary producers support local food webs are not well defined.

The Kimberley coast is uniquely characterized by the very strong dissipation of tidal energy in rugged shelf and coastal topography. Within this system, the relative importance of nutrient inputs from tidally driven cross-shelf mixing, shelf upwelling and seasonal river runoff is unresolved.

The project seeks to characterise the near-shore productivity of a management priority region and link this with ecosystem dynamics at higher trophic levels.

A rich dataset from three cruises undertaken during both wet and dry conditions has been developed, including physical-chemical data, the composition and size fractions of primary and secondary producers and productivity estimates.

To integrate this data into a cohesive framework, shelf - and bay-scale hydrodynamic-biogeochemical models are being developed and tested to explore the fate and distribution of various nutrient sources.

Initially, analyses have been undertaken to identify the lateral extent of riverine influences on pelagic production rates, and to assess how primary and secondary productivity respond to the strong seasonal forcing of the region, including turbidity pulses during the wet season.

The data and models will help establish a rigorous scientific basis for natural resource management in the Kimberley marine estate. The model tools can be further used to assess potential impacts of management measures, ecosystem variability and climate change.

Terrestrial-Ocean Linkages: the role of rivers and estuaries in sustaining marine productivity in the Kimberley

Andrew Revill

Collaborators: Nicole Jones, Richard Silberstein, Miles Furnas, Matt Hipsey, Ryan Lowe
Institutions: CSIRO, UWA, AIMS

The Kimberley region of Western Australia contains more than 100 streams and rivers that discharge significant freshwater (30,000 GL/yr) and associated carbon and nutrients to coastal marine environments during a short period of the summer monsoon season. Inshore and estuarine environments are tightly linked to river flows with strong seasonality as well as high interannual variability. River mouths and estuaries are highly productive habitats that support biodiversity and unique species for commercial, recreational, and indigenous fishing. Productivity in the inshore environment is sensitive to terrestrial runoff that generates turbidity, deposits sediments, and subsidizes marine carbon and nutrient pools.

While the western Kimberley is among the most pristine in Australia, abundant water and energy resources will likely be developed in the near future with important implications for linked river, estuarine and inshore environments.

This project will combine expertise in climate science, catchment rainfall-runoff modelling, and estuarine hydrodynamic-biogeochemical processes to better understand how Kimberley inshore environments are sustained by terrestrial carbon and nutrient sources.

Major outputs include estimates of terrestrial runoff and C, N, P export under current and future climate, and conceptual and numerical models of linked catchment-river-estuary biogeochemistry.

This study will provide critical information on linkages between terrestrial and marine ecosystems and a scientific basis for improved management to promote resilience and minimize the impacts of climate change, catchment development, and commercial and recreational fishing.

This project intends to provide:

- Estimates of the annual freshwater run-off from rivers to coasts
- Estimates of the amount of organic matter supplied from the land to the coast and some understanding of what happens to it in the coastal zone
- Models of what role material from the land plays in coastal ecosystems

and ultimately to identify information which is needed in order to develop better policies for environmental planning and management in the Kimberley

This presentation will outline the methods being used and provide information on progress to date.

Environmental forcing of benthic community productivity within the Kimberley's macrotidal reefs

Ryan Lowe

Collaborators: Renee Gruber (UWA), Jim Falter (UWA), Graham Symonds (CSIRO)
Institutions: UWA, CSIRO

The productivity of tropical reefs is known to be closely coupled to local environmental conditions, including both physical (e.g., water motion, light, temperature) and biogeochemical (e.g., nutrient) variability. However, our modern understanding of these dynamics is based primarily on the large literature of wave-dominated reefs worldwide. Although strongly tidally-forced reefs are prevalent throughout northern Australia (including the Kimberley), the biophysical interactions that occur in these environments still remain unknown. In this presentation, we will describe results from a broad research program investigating: 1) how strong tides interact with intertidal reef platforms to control circulation, ocean-reef water exchange, and temperature variability (project 2.2.1) and 2) how the extreme environmental variability influences the benthic productivity of reef communities (e.g., coralline algae, corals, and seagrasses) living within different zones of a reef (project 2.2.3). The field program specifically focuses on detailed process-studies of an intertidal platform reef (Tallon Island) in the Sunday Island group of the Kimberley, with the goal to use results from this case study to develop predictive models that can be more broadly applied to other reef systems in the Kimberley.

During the first part of the presentation, we will summarise results from an intensive field study to quantify the circulation and temperature variability across the intertidal reef over a spring-neap tidal cycle using an array of synchronized current meters, tide gauges, and thermistors. The results revealed that the presence of the reef terrace significantly limited the exchange of water between the reef and ocean through a hydraulic control that forms along the edge of the reef, allowing the reef to remain submerged over a tidal cycle even when the offshore water level fell 4 m below the reef. A simple analytical model is developed that can accurately predict how water level variability on intertidal reef platforms functionally depends on properties of reef morphology, bottom roughness, and tidal properties, revealing a set of parameters that can be used to quantify how the water depth will fall on a reef during ebb tide, and most importantly whether a reef will dry out.

For the second part of the presentation, we will describe how these physical drivers influence the productivity of the dominant reef communities, as well as the nutrient dynamics across the reef. A series of field experiments were conducted during the Wet and Dry seasons, where continuous measurements of dissolved oxygen and repeated nutrient sampling were used to estimate community-scale rates of production and nutrient uptake. The results are used to quantify the fundamental relationships between rates of net community production/respiration and physical variables (light, temperature and flow). Sampling over diel and tidal cycles also helps elucidate the role of nutrient supply from the coastal ocean versus recycling on these reefs.

Benthic primary productivity: production and consumption of seagrasses, macroalgae and microalgae

Gary Kendrick

Collaborators: Mat Vanderklift, Doug Bearham, James McLaughlin, Lucie Chovrelat, (CSIRO), Andrea Zavala Perez, Bonnie Laverock (UWA), Christin Säwström (ECU), and the Bardi Jawi Rangers
Institutions: UWA, CSIRO, ECU, Bardi Jawi Rangers

This program has characterized the cover, growth and standing stock of major primary producers and the grazing pressure from major grazers: fish and turtles, found in the intertidal lagoons, reefs and mud flats of the One Arm Point coastal region and the Sunday Island Archipelago.

Both inter annual (November 2013, April 2014, October 2014) and seasonal patterns (for seagrasses only: April 2014 – April 2015) in biomass, growth and flowering frequency for the dominant species of seagrasses and macroalgae have been measured at Sunday Island and Tallon Island. Growth rates for seagrass are high, with leaves sometimes exceeding rates of several centimetres growth per day. Growth rates for brown macroalgae are also high, with average growth rates exceeding 1 centimetre per day.

Initial estimates of seagrass consumption showed that much of this growth is eaten by herbivores, with consumption rates sometimes exceeding 100% of the observed growth. High growth rates and relatively low below ground biomass reflect that *Thalassia* in particular is heavily consumed by herbivores, while *Enhalus* has higher above-ground biomass and lower consumption rates.

Patterns in productivity of benthic microalgae have been assessed at Sunday Island and the adjacent mainland during the same surveys. Daily rates of productivity are highly variable, with measurements on consecutive days ranging up to an order of magnitude (e.g. 50-500 mg C m^{-2} d^{-1} at the same site on consecutive days). Overall net productivity was positive in these areas, indicating that they have the potential to contribute significantly to primary production of the ecosystem.

This study is providing a valuable benchmark for future monitoring the health of these habitats that can be applied in Bardi Jawi country and beyond.

Western Australia's Kimberley Marine Parks and WAMSI

Invited Speaker

Tom Hatton

Chair, Marine Parks and Reserves Authority of Western Australia

The Western Australia State Government has an ambitious program aimed at establishing a series of marine parks extending, with few breaks, from the southern end of Eighty-Mile Beach around to the Northern Territory border. Having declared its intent, the State is now engaged in the complex process of developing indicative management plans, co-management arrangements with traditional owners, stakeholder consultation and, ultimately, ministerial approval and gazettal.

Scientific knowledge is an important keystone in developing the plans for these new parks, and the State's 2011 Kimberley Science and Conservation Strategy provided resources to WAMSI to help inform the planning process with the best possible data and understanding. Joint planning of the marine science priorities in fact was completed in 2010. The resulting WAMSI Kimberley Marine Research Program is committed as follows:

The objective of the Kimberley Marine Research Program is to provide a baseline of information for future marine park and reserve management and coastal planning in the region.

and

To be successful, the research projects must be designed to deliver the information that's needed, and the results have to be provided in a form that is useful and usable for managers.

As at 15 March 2015, the Camden Sound MP is gazetted, the gazettal process is well-advanced for Eighty-Mile Beach MP, and the indicative management plans for Roebuck Bay, Horizontal Falls and North Kimberley marine parks are sufficiently advanced that we anticipate their release this year. To date, the KRMP has contributed minimal data or new research understanding to the planning process.

At least some of the explanation for this disconnection is the significant delay between the granting of State resources and the establishment of the projects under the KRMP. This is further compounded by the addition of Horizontal Falls into the conservation agenda, which WAMSI could not have anticipated in 2011. In any event, the opportunities for the KRMP to inform and influence the initial design of the parks, their zoning and their management plans are rapidly closing off.

Given the juncture we are now at, the MPRA's perspective would be to bias the KRMP research program toward improving the effectiveness of the park operations and monitoring of management plan objectives. The MPRA is pleased that the KRMP has formally tasked a Department of Parks and Wildlife regional ecologist to ensure ongoing alignment of the program with the needs of the Kimberley Science and Conservation Strategy as well as supporting the earliest possible delivery of new knowledge to those that need it. In addition to helping assess progress toward each park's management objectives, we would summarise some more general strategic needs as:

- Characterising the natural variability in key ecological drivers and processes;
- Quantifying and characterising the pressures on the ecosystem (and their implications to conservation);
- Improving regional biosecurity, including enhanced detection, risk assessment, and response; and
- Further baseline inventory.

There is inevitable tension between the timing of research delivery and meeting the needs of those who have supported that research. Nevertheless, it is incumbent upon the KRMP to do all that it can to deliver timely and relevant contributions back to the mission they were funded to support. It is the MPRA's hope, and expectation, that as we approach the five and ten-year audits for these new parks (and ultimately the renewals of their management plans), the scientific knowledge generated by the KRMP will be prominent, relevant and available.

Benchmarking human use of Eighty Mile Beach Marine Park prior to implementation of the management plan

Lynnath E. Beckley

Collaborators: Claire B. Smallwood and Emily A. Fisher
Institutions: Murdoch University and WA Department of Fisheries

Human use of the coast between Broome and Port Hedland in north-western Australia was examined by undertaking monthly aerial surveys (November 2012 to October 2013) using a Cessna 210 aircraft and two observers equipped with digital cameras and a GPS logger.

Results with respect to the number of people on the shore and number of boats in coastal waters showed that there was much higher usage in the dry season (May to October) than the wet season (November to April).

Areas with highest densities of people were near 80 Mile Beach Caravan Park, Cape Keraudren and Barn Hill and, to a lesser extent, Port Smith and Bidyadanga. Of the people recorded, 46% were fishing from the shore and 33% were walking along the beach.

Fishing was particularly popular near Eighty Mile Beach Caravan Park with anglers and their associated four-wheel drive vehicles spread along about 30 km of coastline.

Camping along the coast during the dry season was largely within the confines of the large caravan parks at Eighty Mile Beach and Port Smith but there were also nodes of camping at Barn Hill Station and Cape Keraudren.

Boating activity occurred mainly in the northern part around Port Smith and to a lesser extent near Cape Keraudren. These boats were engaged in recreational fishing or motoring and pearling vessels were also recorded between Port Smith and Barn Hill.

The distribution of human use was also examined relative to the sanctuary zones of the new Eighty Mile Beach Marine Park. This study provides spatially explicit data on coastal recreational activities that can be used by managers as a benchmark of use prior to the implementation of the management plan for the marine park.

Spatially explicit delineation of the social values of the Kimberley coastal and marine environment

Jennifer Strickland-Munro

Co-authors: Professor Susan Moore, Dr Halina Kobryn, Dr David Palmer
Collaborators: Department of Parks and Wildlife, University of Western Australia, University of Queensland
Institutions: Murdoch University

Understanding the values that people assign to the natural environment is essential for good resource management. These values influence the decisions people make and just as importantly the decisions they seek to block. The aim of this study was obtain a comprehensive spatial understanding of the suite of values held by stakeholders regarding the Kimberley coast and its waters, between Eighty Mile Beach and the WA-NT border. These values were obtained through 167 in-depth interviews with stakeholders, including Traditional Owners, in the Kimberley, Darwin and Perth. In the interviews respondents mapped the location and extent of their values onto 1:1,000,000 maps and provided comprehensive information on these values as part of their interview.

Analysis involved naming these values post-interviews (using emergent coding), allocating value names to the mapped areas, and determining the most frequently values and spatial concentrations of values. Most frequently mapped values included physical landscape, Aboriginal culture, biodiversity, and therapeutic (i.e. making people feel better mentally or physically) and recreational values. The spatial aggregation of these values shows all the Kimberley coast as valued.

Value hot spots were evident for Roebuck Bay, the western and northern coastal fringes and marine environments of Dampier Peninsula, the Buccaneer Archipelago, Horizontal Falls and Talbot Bay, and Montgomery Reef. A number of other sites northwards also appeared as hot spots, although of less intensity than these areas. The results for the northern Kimberley coast should be treated with caution given the paucity of land-based interviews and lack of involvement of several key Traditional Owner groups at the time this study was conducted.

A number of implications for the future management and development of the Kimberley coast can be derived from these results. The most important of these are:

- Aboriginal peoples' values for the Kimberley coast and marine environments extend well beyond cultural values and as such Aboriginal people must be included in decision making associated with *all* the values of the Kimberley coast.
- Physical landscape values dominated the interviews and were pivotal to peoples' experiences of the Kimberley. Recognition of the importance of this value must underpin all planning and decision making. Future tourism efforts must protect this coast's 'wildness' while also capitalising on it.

Biodiversity was widely and intensely valued, both on- and offshore. This valuing provides an important base for societal support for marine parks and their nature conservation role.

Integrating Indigenous coastal knowledge for marine conservation and management

Albert Wiggan

Nyul Nyul Rangers

Collaborators: Balanggarra Aboriginal Corporation, Wunambal Gaambera Aboriginal Corporation, Bardi and Jawi Niimidiman Aboriginal Corporation, Nyul Nyul, Nyamba Buru Yawuru, Karajarri PBC

Aboriginal people have occupied the Kimberley coastal region for countless generations and have a very strong relationship to country. These communities are considered saltwater country people as they use both coastal and sea resources. Traditional Owners have a rich cultural history and understanding of saltwater country including important knowledge about local environments and patterns of events over extensive periods of time and have used this in their ongoing responsibilities to maintain healthy country.

The Kimberley Science and Conservation Strategy promotes the joint management of the marine environment by Traditional Owners and the Department of Parks and Wildlife through a partnership in the development, monitoring and management of marine parks and reserves.

Local and traditional knowledge has been incorporated into several of the KMRP research projects to assist and complement the knowledge developed by western scientists. At the same time, western science can provide important information that will help indigenous groups manage modern pressures on the marine environment.

This project will be designed to develop frameworks and protocols that will assist in bringing indigenous knowledge and western science together to help better understand and manage the marine environment. This project is proposed to be led by the Traditional Owners of the Kimberley to ensure the recognition and integration of this cultural knowledge and indigenous management practices into western science. A workshop was held in October 2014 with representatives from 6 Kimberley Traditional Owner groups that have responsibility for sea country in the Kimberley. This workshop was used to discuss the project genesis and agree on the project objectives and main focus.

This project will aim to bring Indigenous knowledge into the KMRP and develop a respectful system to support research on Aboriginal country in partnership with Aboriginal people. Both of these elements will assist in developing a shared understanding of country and management practices that will improve joint management of marine protected areas for management agencies and local communities. The project will seek to provide a set of guidelines that can be used for joint management practices for the ongoing management of the Kimberley marine park network. These may include a process for approving research to be undertaken on country, guidelines that will include cultural knowledge and management strategies into joint management practices and greater facilitation of research through skilled support.

Knowledge integration and MSE modelling

Fabio Boschetti[1]

Collaborators: Michael Hughes[2], Hector Lozano-Montes[1], Catherine Bulman[1], Brad Stelfox[4] , Joanna Strzelecki[1]
Institutions: [1]CSIRO, [2]Murdoch University,[3]Alces Group-Canada

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This project aims to develop two computer models to improve our understanding of the likely impacts of increasing human pressure and climate change at a regional scale and to employ the Management Strategy Evaluation framework to engage stakeholders and to communicate the modelling results to key decision makers.

Why would we want to model a region of the size and complexity of the overall Kimberley system? First, a model parameterisation, once completed, constitutes a snapshot of what we know about the system. The actual extent of this knowledge is often laid bare by the very process of model parameterisation. The need to provide a model with a numerical value for (say) turtle biomass and age structure forces the modellers to look for and certify this information if available and to extrapolate credible ranges from other sources if not available. Often it is not until this process is carried out that the extent of our (lack of) knowledge is made clear. Second, since data collection always needs to be prioritised, model sensitivity analysis may provide information on what type of information could provide the largest impact on management-relevant knowledge. Third, the existence of large data gaps at times leads critics to question the value and reliability of a modelling effort. This overlooks the fact that ultimately decisions will have to be made even in the presence of data gaps. Rather than being invalidated by large data gaps, modelling provides a way to recognise, formalise and evaluate the relative impacts of these data gaps. Finally, a vast literature shows that humans, including very bright individuals and experts, can be very poor at predicting how systems behave when they undergo complex dynamics. Computer models help us reducing the extent of these mistakes.

Details about the progress we have made in this project can be found at http://www.wamsi.org.au/research-site/modelling-future-kimberley-region. In particular we draw attention to http://www.alces.ca/files/KimberleyMSE/EwE.htm and http://www.alces.ca/files/KimberleyMSE/Alces.htm. These pages show the parameterisation for Ecopath with Ecosim (EwE) and ALCES, which are used to model the marine and land ecosystems, respectively. Arguably, these pages represent the most accurate summary of what we currently know about the overall Kimberly system. This will be complemented by integrating the knowledge and information generated by other KMRP projects before the model simulations are run and a range of likely and possible future scenarios for the region are explored.

Key ecological processes in Kimberley benthic communities

Mat Vanderklift[1]

Collaborators: Lucie Chovrelat[1], Lisa DeWever[1], Trevor Sampi[2] and Phillip McCarthy[2]

Institutions: [1] CSIRO Oceans & Atmosphere Flagship, [2] Bardi Jawi Rangers

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Herbivores define the state of the Kimberley ecosystem (e.g. heavily-grazed seagrass beds), and have great cultural significance, with odorr (dugong), goorlil (turtle) and several species of aarli (fish) being important food sources for saltwater people.

This collaborative project between CSIRO and the Bardi Jawi rangers is trying to identify which species are key seagrass grazers, and how important seagrass is to their diet.

Observations in of mouth morphology and gut contents in early 2014 indicated that barrbal, or golden-lined spinefoot (*Siganus lineatus*) are potentially important consumers of seagrass on reef flats dominated by turtlegrass (*Thalassia hemprichii*).

Focussed sampling later in 2014 at several sites around Sunday Island collected 30 barrbal. Preliminary analyses from those individuals appear to confirm the importance of seagrass in their diet.

Climate variability and shelf modelling off the Kimberley coast

Ming Feng

Collaborators: Kenji Shimizu, Dirk Slawinski

Institution: CSIRO

In this talk, we will introduce the recent progress in analysing the variability of sea surface temperature, coastal sea level, and precipitation in the Kimberley region, as well as their comparison with the variability in other regions.

Sea level and precipitation variability of the Kimberley coast are highly sensitive to the Pacific ENSO. However, unlike the west coast of Australia, sea surface temperature off the Kimberley coast is not directly influenced by ENSO variability. Due to the decadal strengthening trend of trade winds in the Pacific, toward a La Nina-like condition, there have been fast rising trends of the coastal sea levels off the Kimberley coast over the past two decades. During the same time period, precipitation rates in the region have also enhanced, influenced by the dominant La Nina condition. Sea surface temperature off the coast has moderate rising trend over the past 30 years, mostly in the austral winter.

The decadal climate trend in the Pacific has induced more frequent marine heat wave events off the coast of Western Australia, likely due to the enhanced upper ocean heat content off the north-west coast, inducing more frequent cyclonic wind anomalies and strengthening the Leeuwin Current transport. Most of the marine heat wave events occurred off the west and the north-west coast of Western Australia, however it is yet to know if the marine biota of the Kimberley coast have adapted to the low ocean temperature variability in summer.

A Regional Ocean Modelling System (ROMS) model, developed by CSIRO and nested within the CSIRO Bluelink OFAM 10-km resolution model simulation, is used to simulate the shelf circulation of the Kimberley coast including tidal currents. The model has been validated to using IMOS mooring data and will be used to understand the variability of the shelf circulation and cross shelf exchange, and deliver the climate change projections.

Thermal tolerance of corals adapted to a highly fluctuating, naturally extreme environment

Verena Schoepf [1,2,3]

Collaborators: Michael Stat [2,4,5], James L. Falter [1,2,3] and Malcolm T. McCulloch [1,2,3]

Institutions: [1] School of Earth and Environment and ARC Centre of Excellence for Coral Reef Studies, The University of Western Australia, Crawley, WA, Australia

[2] UWA Oceans Institute, The University of Western Australia, Crawley, WA, Australia

[3] The Western Australian Marine Science Institution, Perth, WA, Australia

[4] Centre for Microscopy, Characterisation and Analysis, The University of Western Australia, Crawley, WA, Australia

[5] Department of Environment and Agriculture, Curtin University, Bentley, WA , Australia

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Corals living in naturally extreme thermal environments can provide important insights into the processes driving thermal tolerance and thus resistance to coral bleaching and climate change. Here, we determined the thermal tolerance of corals growing in the remote and little-known Kimberley region of northwest Australia, which represents a unique, naturally extreme environment characterised by up to 10 m tides, extreme temperature fluctuations (up to 7°C per day, maxima up to 37°C) and frequent aerial exposure of intertidal corals.

We conducted a heat stress experiment using two common corals with differing morphologies, branching *Acropora aspera* and massive *Favia* sp. Both species were collected from two environments (intertidal and subtidal) that differ regarding daily temperature variation and temperature extremes.

Corals were maintained under realistic flow speed at ambient temperatures and ambient +2 and +3°C, respectively, for 11 days. All treatments included a daily temperature variation of 4-5°C. Based on measurements of photochemical efficiency, chlorophyll *a* concentration, symbiont density, tissue biomass and survival, we determined that the bleaching threshold of these Kimberley corals lies between 32-33°C (daily mean temperature) and thus about 1-2°C above the maximum monthly mean temperatures of ~31°C at our site.

Generally, *Acropora* was much more susceptible to bleaching than *Favia* and experienced up to 75% mortality, whereas all *Favia* corals survived. Further, subtidal corals from both species were generally more susceptible to bleaching than intertidal corals.

Given that all corals hosted *Symbiodinium* clade C (predominantly chloroplast 23S rDNA type Cp1) independent of treatment or their original environment, this shows that the thermal environment plays a key role in providing increased resistance to heat stress. These findings confirm that highly fluctuating rather than high mean temperatures determine coral thermal tolerance, yet demonstrate that corals adapted to such extreme thermal environments are nevertheless highly vulnerable to climate change.

Changes in coastal water quality in the Kimberley as inferred from palaeoecological studies

John Keesing

Collaborators: Yajun Peng, Dongyan Liu
Institutions: CSIRO and the Chinese Academy of Sciences

This study employs palaeoecological and biogeochemical methods to infer historical changes in water quality from sediment cores taken in coastal waters in the Kimberley.

At each of the sites sampled we have attempted to compare gradients of human use or natural environmental variability in addition to looking for long term environmental changes. These sites are Cygnet Bay (comparison of pearl farm/non pearl farm sites), King George River (comparison of embayments with high / low riverine input), and Roebuck Bay (comparison of sites near/far from Broome's anthropogenic inputs.

To date only results from the Cygnet Bay samples have been obtained. Pearl oyster aquaculture, with a 50-year history in Australia, has been regarded as an anthropogenic activity with low environmental risk, however we found that small disturbances accumulated over a long period can be detected.

Our cores reflected an 80-year record of environmental processes and with knowledge of the changes in farm practices over 50 years we were able to reconstruct a time series of change in biogeochemical parameters which can be related to changes in water quality. Sediment cores taken inside and outside a pearl farm displayed contrasting characteristics after the start of farming in the 1960s.

Total organic carbon, total nitrogen, biogenic silica, and fine-grained sediment inside the farm increased significantly over time. The ranges of C/N, $\delta^{13}C$ and $\delta^{15}N$ discriminated that the origin of increased organic matter were from autochthonous sources rather than allochthonous input.

Our analysis detected significant changes responding to the development of pearl farming rather than variations in rainfall and temperature. Modern long line pearl culture since the late 1980s was presumed to be a dominant driver of the changes we observed, accelerating the increase of organic matter in the sediments by reducing water flow, altering sediment grain size and increasing nutrient flux. In contrast, only small variations in response to increased rainfall over time occurred outside the farm. Geochemical ratios between the two sites showed pearl farming on decadal time scales, even at low density, can cause environmental change with a two to four-fold increase in organic matter, although consistent with environmental studies on surface sediments at the same sites, there is no suggestion that any environmental damage or ecological changes have occurred.

Going with the Flow: Ecological Connectivity in the Kimberley Marine Environment

Oliver Berry

Co-authors: Oliver Berry[1], James Gilmour[2], Kathryn McMahon[3], Glenn Moore[4], Zoe Richards[4], Mike Travers[5], Jim Underwood[2]

Collaborators: Bardi Jawi Traditional Owners, Bardi Jawi Rangers, Mayala Traditional Owners

Institutions: . [1]CSIRO Oceans and Atmosphere Flagship, [2]Australian Institute of Marine Science, [3]Centre for Marine Ecosystems Research, Edith Cowan University, [4]Western Australian Museum, [5]Department of Fisheries

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The coral reefs in the Kimberley region of Western Australia are of great regional and international significance due to their high diversity and their inherent tolerance of harsh environmental conditions. Yet, we have limited understanding of the bio-physical processes that sustain them, including the importance of linkages among reefs and between reefs in the Kimberley and those elsewhere. This project is employing genomic tools and microchemistry to provide the first comprehensive investigation of the spatial scale of ecological connectivity in the Kimberley marine environment.

So far the WAMSI Ecological Connectivity project has conducted the following activities:

<u>Selection of focal species</u>: We have identified model taxa that are representative of life-histories common in Kimberley marine systems, form key habitats, and/or are important for indigenous or commercial harvest (fishes, corals, seagrasses, trochus).

<u>Fieldwork</u>: During two field trips in August and October 2014, and in collaboration with traditional owners and sea rangers, we conducted a hierarchical sampling design encompassing the northern Dampier Peninsular and the Buccaneer Archipelago. Genetic samples from 5370 individuals from 22 sites were collected. Sampling sites were arranged at distances that were both practical to sample, and likely to represent meaningful distances for the investigation of larval transport.

<u>Genomic analysis</u>: We have initiated genotype-by-sequencing analysis for the majority of the focal species. We are targeting 500-5000 single nucleotide polymorphisms (SNPs) DNA markers per species, which will provide high power to characterise connectivity, as well as offer opportunities to identify adaptive differences between reefs.

The outputs of this project will enable a better understanding of the drivers of biodiversity pattern and process in the Kimberley, and specifically the levels of interdependence between reefs, and will contribute to the spatial management of marine protected areas and off-reserve assets in this remarkable region.

Department of Fisheries, Western Australia: Research, Monitoring and Assessment in the Kimberley region of the North Coast Bioregion

Invited Speaker

Brett Molony
Research Division, Department of Fisheries, Western Australia

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Department of Fisheries (DoFWA) uses an Ecosystem Based Fisheries Management (EBFM) risk-based approach to prioritise monitoring and assessment of the State's aquatic resources. The Kimberley region's tropical ecosystems and habitats support a unique biodiversity that supports important commercial, recreational and indigenous fisheries. The region also houses major coastal and maritime infrastructure, with more likely in the future. This tropical system is also characterised by macro tides and cyclones and is exposed to climate change.

With a wide array of natural resource management components and responsibilities under its jurisdiction, the monitoring assessment and research program of DoFWA is diverse. Some recent highlights and future work scheduled for the next few years include;

- Completed Marine Stewardship Council (MSC) pre-assessments for all commercial fisheries, including those in the Kimberley region. Outcomes of pre-assessments have identified additional areas for potenital investment;
- Monitoring and assessment of all northern fisheries, including scheduled otolith collection phases and stock assessments;
- Ongoing baseline surveys in Lalang-Garram Camden Sound Marine Park to underpin EBFM in the Kimberley;
- Ongoing monitoring of marine pests and invasive species in key locations;
- Biennial State-wide program to estimate recreational catches of boat-based fishers to monitor effort and catch. Two surveys have been competed with a third commencing in late 2015. These data support DoFWA's Integrated Fisheries Management;
- Supporting fisheries to meet conditions and recommendations under DotE's EPBC Act to maintain export accreditation;
- Monitoring piggy-back spat to provide robust estimates of future commercial catches and set sustainable quotas;
- Providing support and advice to DoFWA's clients, including WAFIC, Recfishwest, DPaW, DotE, AFMA, BRS and other Agencies;

- Leading and supporting research with a range of research partners
- Identifying gaps and potential opportunities for future research;
- Supporting fisheries to move to full MSC certification.

With a new Fisheries Act likely, the needs of management for robust and timely research advice will become even more critical into the future

Marine Turtles of the Kimberley- WAMSI Project 1.2.2

Scott Whiting

Co-authors: Scott Whiting[1], Tony Tucker[1],Nicki Mitchell[2], Oliver Berry[3], Nancy FitzSimmons[4], and Kelly Pendoley[5]
Collaborators: Miriuwung Gajerrong, Balanggarra Aboriginal Corporation,Wunambal Gaambera Aboriginal Corporation, Dambimangari Aboriginal Corporation, Nyul Nyul, Karajarri PBC, Nyangumarta Warrarn

Institutions: [1]Department of Parks and Wildlife, WA , [2]School of Animal Biology, The University of Western Australia, [3]CSIRO Oceans & Atmosphere, [4]Griffith School of Environment, Griffith University, Nathan QLD, [5]Pendoley Environmental Pty Ltd, WA

Marine turtles are long lived and have complex life histories that include the use of multiple habitats over large geographical scales. Globally, they are highly valued by the general public, indigenous and subsistence communities and the scientific community. Despite these values there are many gaps in our understanding of marine turtles, especially in the Kimberley of Australia, where limited knowledge of the distribution and abundance of nesting species inhibit development assessments, management planning and the establishment of long term monitoring. For these reasons the WAMSI turtle project has focused on the nesting phase of the life history including the following three components:

1) inventory of distribution and abundance of species through surveys and Indigenous Knowledge;
2) stock identification using genetics; and
3) the impact on nesting from temperature increases through climate change.

The WAMSI turtle project has conducted the following activities:

- engagement with Indigenous groups across the Kimberley to establish agreed work plans;
- aerial surveys of most Kimberley beaches in summer and winter;
- on- ground track verification across the Kimberley from Eighty Mile Beach to Cape Domett;
- collection of turtle genetic material across most of the Kimberley; and
- collection of eggs for climate change impact experiments and sex ratio studies.

Current outputs of the project include a completed honours thesis, one published scientific paper, three conference presentations, community posters and presentations and more than ten meetings and presentations to Indigenous groups. Outputs also include shared aerial images with the WAMSI Crocodile and Reef Geomorphology projects.

Expected management outcomes of this project will directly inform the assessment of development projects, planning of Marine Park zones and management plans and assist in establishing long-term monitoring. Genetic analyses will define the stocks while the climate change component will assist in predicting future impacts to these stocks. Both components will assist in planning for management and establishing a monitoring program.

Modelling the movement and spatial distribution of humpback whales in the nearshore waters of the Kimberley

Michele Thums[1]

Collaborators: Mark Meekan[1], Curt Jenner[2], Kelly Waples[3]

Institutions: [1]Australian Institute of Marine Science, [2]Centre for Whale Research, [3]Western Australia Department of Parks and Wildlife

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Off the west coast of Australia, a population of approximately 33,000 humpback whales migrate annually from summer feeding grounds in Antarctica to breed and calve during winter in the nearshore waters of the Kimberley. Management of humpback whales here is hampered by a lack of integrated approaches to data acquisition and analysis.

Extensive aerial and vessel survey and some tagging programs have been conducted over the last decade, by industry, tourism, community groups, Coastwatch, the Centre for Whale Research (CWR) and WAMSI but there has been limited attempt to use these data to quantify the spatial distribution and identify critical habitat across the Kimberley; information that is urgently required to better inform management in an ecosystem that faces challenges of warming environments, massive industrial development and rapid growth of humpback whale populations.

To address this need, we have collated the vast majority of data collected on humpback whale distribution in the Kimberley. This huge dataset, spanning two decades will be synthesised to understand their distribution and critical habitat requirements, particularly the core areas for calving and nursing, which remain poorly defined.

One of the first stages of the project was to determine the best analyses (given the data) to meet the objectives. The data collected by CWR has been done in a systematic way allowing for a range of analysis techniques. However many other data sources have no associated survey path, effort or environmental condition data, limiting the options for analysis.

In order to make best use of the temporal coverage in the data, we will use a predictive spatial habitat model using the Maxent (or similar) method. We will analyse the survey data collected from different platforms separately and after first examining annual differences in distribution we will combine the years.

Our preliminary analysis shows females and calves associated with areas where there is some stratification in surface water temperature. The overarching goal of this project is to identify and characterise the ecologically significant areas for humpback whales in the Kimberley with a key focus on better defining and describing calving areas. We will also use this synthesis to identify research gaps to inform future monitoring and where possible, provide estimates of relative abundance.

Monitoring of saltwater crocodiles in the Kimberley

Andrew Halford

Collaborators: Winston Kay, Kelly Waples, Todd Quartermaine, Jarrad Holmes, Danny Barrow

Institutions: Western Australia Department of Parks and Wildlife

Over the past 30 years, considerable research has been conducted on saltwater crocodile (*Crocodylus porosus*) biology, population dynamics and recovery from hunting, (DEC 2009). However, the geographic focus has been the Northern Territory (NT) with only the Cambridge Gulf region in Western Australia receiving any attention.

The last broad scale surveys conducted on saltwater crocodile populations in the greater West Kimberley region were done over 25 years ago by Messel et al. (1987). At this time total population numbers were estimated at ~ 2,500 adults and represented a population slowly recovering from the excessive harvesting that was ended by the WA Government in 1969 (Semeniuk et al. 2011). The research conducted on saltwater crocodiles in the NT concluded that their populations had fully recovered by 2000 (Webb et al. 2000). However, the only conclusions that can be drawn from the paucity of data on WA populations are that saltwater crocodiles likely currently occupy their historical ranges and are not under any known local pressures. Climate change does, however, have the capacity to cause regional-scale impacts on crocodile breeding and sex-ratios while warming oceans are also likely to increase southward incursions of crocodiles down the Kimberley and Pilbara coastlines.

With respect to *C. porosus* habitat, the Kimberley region differs from the NT in that it has far less appropriate habitat for nesting/breeding. River systems that pass landwards into savannah supratidal flats and savannah floodplains provide the most productive environments for crocodiles, allowing for significant nesting (Semeniuk et al. 2011). Apart from the Cambridge Gulf region there is much less of this type of seascape/landscape available throughout the greater Kimberley Region. In the western Kimberley, the largest *C. porosus* populations occur in the Prince Regent and Roe River systems (Semeniuk et al. 2011) where appropriate nesting habitat is most abundant. This restricted distribution of appropriate nesting habitat is an advantage from a monitoring perspective in that fewer areas need be targeted to gain effective insights into the "health" of *C. porosus* populations in the greater Kimberley region.

Fortuitously, these systems are also adjacent to each other which enables resources to be concentrated in the one area. Utilising night time spotlight surveys, which are standard practice in the Northern Territory and were used by Messel et al. during the 1987 surveys, we shall be undertaking detailed counts of saltwater crocodile populations in the Prince Regent and Roe Rivers systems in August 2015. This data will be used to draw direct inferences with the Messel et al. surveys to ascertain the changes that have occurred in the crocodile populations of the greater Kimberley over the past 25+ years. Because surveys of the entire Kimberley Region are not practical it is also intended to build a predictive capacity through modelling of the data collected from the targeted surveys. Modelling work on NT *C. porosus* populations has identified a suite of environmental parameters that correlate well with the abundance of saltwater crocodiles (Fukuda et al. 2007). This combination of targeted surveys and modelling of saltwater crocodile abundances in the greater Kimberley region will provide a significant update to our understanding of current baseline conditions of *C. porosus* populations, enabling managers to formulate plans based on current rather than historic data.

Integrating Indigenous knowledge and survey techniques to develop a baseline for dugong (*Dugong dugon*) management in the Kimberley (Project 1.2.5).

Mat Vanderklift

Co-authors: Peter Bayliss, Chris Wilcox & Mat Vanderklift
Collaborators: Balanggarra, Wunambal Gaambera and Dambimangari coastal Kimberly communities, DPAW
Institutions: CSIRO

The dugong (*Dugong dugon)* is listed as vulnerable to extinction globally and Northern Australia is home to the largest remaining populations. Whilst they occur from Shark Bay through to the Kimberley and across to the NT border, there is limited information on their seasonal distribution and abundance in the Kimberley representing a significant knowledge gap. Dugongs are considered an important keystone species ecologically and they are culturally significant to many Indigenous communities providing a valuable food source. There is a deep cultural knowledge of dugongs in the Kimberley, including an understanding of seasonal changes in their distribution and abundance. Currently there are limited human-induced threats to dugongs in the Kimberley, making the region an important global and national stronghold for the species. Threats may include habitat loss from future development pressures and associated increases in local human populations. All current and future cumulative risks to dugong populations, including the potential for unstainable harvests, will need to be placed into perspective using monitoring and assessment frameworks that are underpinned by both scientific knowledge and Traditional Ecological Knowledge. Management of marine parks and Indigenous Protected Areas (IPAs) in the Kimberley will therefore need to address potential cumulative impacts in the face of increasing development pressures and concomitant local human populations.

Given this context our project aims to integrate Indigenous knowledge and existing and new data to better understand dugongs in the Kimberley in order to determine how best to monitor and manage them into the future. The seasonal distribution and abundance of dugongs will be ascertained at regional scale using well established aerial survey methodology, and individual movements of dugongs will be studied using satellite tagging technology in proposed marine reserves and areas relevant to Indigenous Sea Country Plans. We will commence in the northern Kimberley region in partnership with the Balanggarra, Wunambal Gaambera and Dambimangari Aboriginal Corporations and their associated ranger groups. The project area will be extended to the southern Kimberley and through to Port Hedland depending on available resources.

Progress to date: research partnerships with relevant Indigenous ranger groups for the dugong project underway; development of a 3-day aerial survey training package for Indigenous rangers underway (includes survey design, logistics, data storage & management, GIS mapping, basic analysis & test flights); cultural maps of dugong hunting areas currently being obtained for the 3 northern communities and will be incorporated in the regional survey design using Bayesian approaches; and 10 satellite tags have been purchased. The aerial survey team will comprise 2 Indigenous rangers from each group and 2 CSIRO staff. The design of the baseline regional survey will be completed by May, the training program undertaken in September and the actual survey October through to November.

Relative abundance, population genetic structure and acoustic monitoring of Australian snubfin and humpback dolphins in regions within the Kimberley

Lars Bejder

Co-authors: Lars Bejder[1], Simon Allen[1], Alex Brown[1], Chandra Salgado Kent[2], Josh Smith[1] and Deborah Thiele[3] and Sarah Marley[2]

Institutions: [1]Murdoch University, [2]Curtin University, [3]Australian National University

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There are insufficient data on the Australian snubfin (*Orcaella heinsohni*) and the Australian humpback (*Sousa sahulensis*) dolphin populations in Western Australia for the Department of Parks and Wildlife to assess whether they should be listed as Threatened or Specially Protected under the *Wildlife Conservation Act 1950*. We are integrating complementary sampling techniques (photo-identification, genetic sampling and passive acoustic monitoring) to:

1) provide insight on the relative abundance of snubfin and humpback dolphins in Cone Bay and one other remote location in the eastern Kimberley;
2) assess the genetic connectivity of snubfin and humpback dolphin populations between these locations and previously sampled populations in the Kimberley;
3) develop and test Passive Acoustic Monitoring (PAM) methods as a cost-effective monitoring technology to obtain information on species occurrence and habitat usage in remote areas.

In September 2014, photo-identification and genetic (biopsy) data were collected on these two species within the 100-km^2 study area of Cone Bay in collaboration with Dambimangari Rangers. While following pre-determined transects, we encountered 26 dolphin groups, ranging from one to 13 individuals. Additionally, we opportunistically encountered 31 groups while transiting the area or searching for dolphins specifically for biopsy sampling.

Humpback dolphins were the most regularly encountered, totalling 37 groups overall, while a total of 20 snubfin groups were encountered. We obtained biopsy samples from a total of eighteen dolphins (9 snubfin, 9 humpback). Molecular analyses of these tissue samples will provide estimates of genetic diversity and connectivity between sampled populations elsewhere in north-western Australia.

The Dambimangari rangers were given an introduction to our research and were briefed on the techniques of running transects, photo-identification and genetic sampling. They received training in systematically searching for dolphins, recording location, behavioural and environmental data, along with taking photo-identification images of dolphins.

We are exploring opportunities for a second field trip to the Kimberley later in 2015.

In May, July, August, and September/October 2014, acoustic sampling was undertaken to contribute to an ongoing project investigating the potential application of passive acoustic monitoring for snubfin and humpback dolphins. In May, this was undertaken concurrently with independent boat based surveys of both species in Cygnet Bay. In total, 10 of the 21 snubfin dolphin groups encountered and 5 of the 13 humpback groups encountered were acoustically sampled, amounting to approximately 3 hours of dedicated recordings. This will, in combination with other recordings, contribute to a comprehensive acoustic repertoire catalogue.

In July, acoustic recordings were undertaken concurrently with vessel surveys in Roebuck Bay. Acoustic recordings were made over 408 hrs during 27 days using a fixed acoustic logger sampling at a rate of 192 kHz and recording for 600s every 900s. In addition, 116 in-situ recordings were made during boat-based surveys using a hand-held hydrophone.

During 16 days, we encountered 375 snubfin dolphins (incl. recounts) in 102 groups and 16 humpback dolphins in 3 groups. Yawaru rangers assisted in surveys and received training.

The September fieldtrip (Roebuck Bay) focussed on determining detection limits for snubfin dolphin vocalisations (analyses underway). Movements of snubfin dolphins were recorded using a digital SLR and GPS compass from a moored vessel while acoustic recordings were obtained from an array of 4 hydrophones spaced equidistantly around the vessel and a fixed acoustic logger. In total, 78 groups of snubfin dolphins were encountered and 55 hours of acoustic recordings were obtained.

Shorebird monitoring in north-western Australia

Danny Rogers

Collaborators: Chris Hassell[2], Darren Stevens[3], Golo Maurer[4]

Institutions: [1]Australasian Wader Studies Group, [2]Global Flyway Network, [3]Department of Parks and Wildlife, [4]BirdLife Australia

The huge tidal flats on the shores of north-western Australia support the largest non-breeding populations of shorebirds in Australia. Indeed the region is one of the most important shorebird sites in the world; it is used by >40 shorebird species, with >650,000 shorebirds foraging on the tidal flats, and a further 2.5 million grassland shorebirds intermittently using the beaches as thermal refuges.

Most of these shorebirds are migrants from breeding grounds in the northern hemisphere (listed as matters of national significance under the EPBC Act) and they use the Kimberly coast as a non-breeding site where they can carry out their annual moult and then put on the huge fuel supplies required for northwards migration.

This presentation describes the approach that the Australasian Wader Studies Group has used to monitor these shorebird populations. We provide brief examples of how the data generated can be used to inform both local management, and to address research issues of global concern to shorebird conservation.

Remote Sensing

Peter Fearns

Collaborators: Nick Hardman-Mountford[2], Mark Broomhall[1]

Institutions: [1]Curtin University, [2]CSIRO

The Kimberley is vast, remote and potentially very expensive and dangerous to undertake any on-ground monitoring activities in. Remote sensing can provide large-scale synoptic views on a regular basis, as well as relatively high resolution views of specific regions at lower temporal frequency.

With respect to monitoring condition and pressure metrics in support of DPaW management activities, we are interested in determining the potential of remote sensing technologies.

We have reviewed the condition and pressure metrics, and compared these to a range of remote sensing technologies and products. The highest potential for remote sensing methods to support DPaW monitoring is in the monitoring of water clarity, particularly in terms of its impact on the light levels and light quality in shallow coastal waters. Also of high importance is the monitoring of ocean temperature.

Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite data are available on a near-daily basis for the entire globe at spatial resolutions of 250 m to 1000 m. However the presence of cloud, particularly in the tropical north, obscures space-based views of the earth. On average, approximately 2 to 3 reasonable views of any region are possible each week, but this varies with season. Other sensors such as Landsat can provide higher resolution images, 15 m to 30 m, however the sampling frequency is only once every 16 days.

The aims of this work are to determine the appropriate spatial and temporal resolutions of remote sensing data that will adequately support monitoring of assets in the Kimberley. We are also interested in the accuracy of remote sensing products and how the data may be interpreted to describe environmental condition as well as monitor change in condition over time.

Analysis of long term archives of satellite data can provide descriptions of spatial trends in water quality. We can identify “hot spot” regions. These may be locations of extreme temperature events, relevant to coral bleaching, or extreme turbidity events, relevant to the impact of reduced light levels on photosynthesising organisms.

This project will utilise MODIS and Landsat satellite data to produce regional maps of water clarity and water temperature. The maps will include information such as long-term averages, seasonal cycles, and occurrence of extreme events.

The spatial and temporal patterns elucidated using remote sensing data can be of value to ecosystem researchers to help improve understanding of spatial distributions of ecosystems, as well as changes in ecosystem condition. Identification of hot spot regions can help DPaW target their intensive in-situ monitoring programmes.

Additional Student Abstracts

Geomorphic Patterns, Habitats and Substrates of Macrotidal Reefs from the Kimberley, North West Australia

Student Poster

Moataz Kordi

Collaborators: Lindsay Collins, Alexandra Stevens

Institution: Curtin University

Coral reefs occur extensively along the north-western coast of Australia in the Kimberley Bioregion (KIM), forming major geomorphic features (landforms) along and just off the coast. These reefs have not been studied in as much detail as the offshore reefs and are poorly known. Geomorphological and surficial cover substrates and habitats maps of coral reefs provide significant information to both researchers and managers about the distribution and extent of reef landforms.

This study aims to provide some of the first detailed analysis of reef geomorphology, distribution and environments. Remotely sensed images were used to extract information as well as other multiple data sources which were integrated using a Geographic Information System (GIS) to verify results and to add value to the data in order to produce consistent, accurate, and useful geomorphic maps. The outcomes will facilitate understanding of reefs in this region and be utilised to develop a reef geomorphic classification scheme which describes reef evolution, classification and distribution of reefs by type. The study will provide a robust foundation to foster further work in various disciplines seeking to improve knowledge of these biodiverse yet poorly known macrotidal reef systems.

Sub-bottom profiling and growth patterns of Kimberley coral reefs, North West Australia

Student Poster

Giada Bufarale

Collaborators: Lindsay B. Collins, Michael O'Leary, Moataz Kordi, Tubagus Solihuddin, Alexandra Stevens

Institution: Curtin University

The Kimberley region is located on the north western continental margin of Australia and is characterised by unique and complex geology and geomorphology, significantly influenced by the macrotidal range systems (up to 11 m), which result in expansive intertidal zones.

A total of 300 km of high-resolution shallow imaging data were acquired during a sub-bottom profiling (SBP) study of various southern Kimberley reef settings. Acoustic datasets were collected with a Boomer SBP system covering reefs where remotely sensed images were previously used to produce geomorphic and substrate classification maps.

A classification diagram has been developed on the basis of imaging of internal structures. Vertical and lateral differences were identified and categorised according to their shape and acoustic reflection characteristics along the hiatuses and internal reflectors.

These new datasets have provided a better understanding of Quaternary reef growth. The pre-existing substrate has influenced the successive morphology of fringing reefs, intertidal platforms and platform reefs. Global sea-level change, controlled by ice age fluctuation events, provides a signal which is recorded in successive stages of the reef growth separated by hiatuses.

Two acoustic reflectors can be consistently distinguished across the inner shelf reefs (Sundays Group, Buccaneer Archipelago and Montgomery Reef), marking the boundaries between Holocene reef (Marine Isotope Stage 1, MIS1, last 12,000 years) commonly 10-15 m thick, and MIS 5 (last 125,000 years) and an ancient Neoproterozoic rock foundation over which Quaternary reef growth occurred. Three acoustic horizons characterise the offshore reefs (Adele complex), highlighting multiple reef building stages.

Spatial distribution of coastal access tracks and trails in the western Kimberley

Student Poster

Halina T. Kobryn

Collaborators: Lynnath E. Beckley & Daniel Gibbons

Institutions: Murdoch University

The proliferation of informal access tracks enables unmanaged recreational activity in remote coastal areas and such tracks can directly and indirectly impact the coastal environment.

With the aim of enhancing the capacity of conservation managers to address this problem, coastal access tracks in the western Kimberley region of northern Australia were mapped using recent, high resolution ALOS panchromatic satellite imagery.

We mapped tracks within the 10 km buffer of the Mean High Water Mark and track density was evaluated in relation to proximity to settlements and main roads. Tracks accessing the shoreline were analysed per shoreline type. We mapped a total of 1,600 km of coastal tracks and nearly 1000 coastal access points.

Significant differences were found between areas east and west of King Sound; only 10% of tracks and 14 coastal access points were east of King Sound. There was also a large, significant difference in average track disturbance density between the study area to the east (9 m^2/ha) and west (89 m^2/ha) of King Sound.

Track densities were examined for potential association with variables such as tenure, type of coast, distance from settlements and main roads. We found that land tenure classes that restrict human access, the relative attractiveness of geomorphology, and a travel impedance effect related to the proximity of formal roads and isolated human structures, are factors that significantly influence the spatial distribution and density of coastal access tracks.

On the basis of these findings, we make several recommendations with respect to the management of coastal access tracks in the western Kimberley.

A model-based decision support tool for managing Lyngbya occurrence in intertidal coastal environments

Student Poster

Gayan Gunaratne

Collaborators: Matthew Hipsey and Ryan Vogwill

Institutions: Department of Parks and Wildlife, West Kimberly District, Broome; Roebuck Bay Working Group, Broome; and Rangelands Natural Resource Management

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Extensive blooms of *Lyngbya Majuscula* (hereafter Lyngbya) have been recorded in tropical coastal waters across the globe in recent years, including Roebuck Bay hypertidal embayment in north-western Australia. Such blooms are driven by environmental changes, primarily anthropogenic input of nutrients, and threaten coastal ecosystems as well as being harmful in instances of human contact. Hypertidal environments generally discourage algal blooms with strong vertical mixing and strong flushing capacities. Somewhat paradoxically Lyngbya persists in the Roebuck Bay intertidal zone.

Understanding why this is occurring is challenging because the causes of Lyngbya blooms are complex and multifaceted; there is a general lack of data in many similarly remote areas and the logistical difficulties associated with data collection in remote and ungauged environments.

This study attempts to understand why blooms are occurring using novel community based data collection and numerical modelling to ascertain the climate, ecological and physical processes affecting Lyngbya blooms.

Firstly, the portion of Roebuck Bay's catchment, in which the urban areas of Broome occur, was instrumented to quantify nutrient export to Roebuck Bay. This showed a distinct seasonal first flush with an initial 30% of runoff volume containing 40-70% of the nutrient load, resulting in periodic shock loading of nutrients to the bay at the onset of the wet season.

Secondly an ecohydrological model was developed to predict Lyngbya biomass to support management decisions. The model structure is based on three key state variables of Lyngbya biomass; 1) benthic submerged, 2) exposed and 3) floating. It links these three states with key environmental factors for growth.

The mechanistic nature of the model means it can be used to assess the relative risk of Lyngbya accumulation for different scenarios. This model can be used as a framework for setting Lyngbya management priorities in Roebuck Bay and as a basis for future research into this and other coastal ecosystems affected by Lyngbya blooms.

ReefKIM, an integrated geodatabase of nearshore reef along the Kimberley coast, WA

Student Poster

Alexandra Stevens

Collaborators: Professor Lindsay Collins, Moataz Kordi

Institutions: Curtin University

The Kimberley coast, in the north west of Australia, is bordered by an extensive area of coral reefs. These vital ecosystems are poorly studied and in need of detailed understanding to aid and improve conservation and management. The remoteness and macrotidal regime of the area play significant roles in making study and management of this coast a challenging task. The aim of this work is to construct a geodatabase of the Kimberley reefs (ReefKIM) based on data fusion utilising GIS.

Data inputs into this geodatabase were varied and included bathymetric charts, remotely sensed images, georeferenced fieldwork photos, ground truth and data from other sources. The data inputs also include information on environmental, geological, geomorphological, biological, chemical, physical, oceanographic and climatic factors. Compiling these factors and conditions into one consistent georeferenced database facilitates presenting them as features on a dynamic map associated with an attribute table. The outcomes present how the geodatabase can improve the process of studying and managing the reefs of the Kimberley region.

ReefKIM provides essential information on geological and ecological characteristics such as mapping, representation, connectivity and biodiversity of the Kimberley coral reefs. Furthermore it permits a comparison of these reefs with other reef systems in the world, such as the Great Barrier Reef, to gain a better understanding of reef growth in this region.

Influence of oceanography on Kimberley krill assemblages

Student Poster

Alicia Sutton

Collaborators: Prof Lynnath Beckley

Institutions: Murdoch University

The tropical north-west of Australia boasts a marine environment with a diverse array of biota as well as highly dynamic oceanography because of large tidal fluctuations, seasonal monsoons, tropical cyclones and El Niño influences.

Krill, as part of the holoplankton, are influenced by such oceanographic conditions. An investigation off the Kimberley coast during the austral autumn of 2010 revealed 20 species of krill, of which three, *Euphausia fallax*, *Euphausia sibogae* and *Nematoscelis gracilis*, were identified as new records for the region.

Although the number of species increased from shelf to oceanic waters, concentrations of krill decreased.

Pseudeuphausia latifrons was the most abundant species off the Kimberley coast, with concentrations highest in shelf waters sampled during the night ($2.84 \pm 1.95\ m^{-3}$). This species was also the most abundant at the 100 m and 200 m isobaths, but *Stylocheiron carinatum* dominated in the deeper waters (500 m, 1000 m and 2000 m stations).

In terms of environmental influences on the krill assemblages, together mean seawater density, zooplankton settled volume and depth provided the highest correlation with krill assemblages ($r^2 = 0.69$, $P = 0.002$).

Mean seawater density was used as an indicator for water masses, and two distinct water masses were identified in the study area, a warmer (> 30°C), higher salinity (> 34.7 psu) surface layer overlayed a cooler, less saline layer.

The Kimberley coast is one of the least studied marine environments of Australia, particularly for zooplankton, and this study improves the understanding of oceanographic influences on krill diversity and distribution in this highly dynamic environment.

Going with the Flow: Ecological Connectivity of the seagrass *Thalassia hemprichii* in the Kimberley and North West Cape, Western Australia

Student Poster

Authors: Udhi Hernawan[1], Kathryn McMahon[1], Kor-Jent van Dijk[2], Gary Kendrick[3], Paul Lavery[1], Oliver Berry[4], Mike Travers[5] and Jim Underwood[6]

Collaborators: Bardi Jawi Traditional Owners, Bardi Jawi Rangers, Mayala Traditional Owners

Institutions: [1]Edith Cowan University, [2]University of Adelaide, [3]University of Western Australia, [4]CSIRO Oceans and Atmosphere Flagship, Floreat, Western Australia, [5]Department of Fisheries, [6]Australian Institute of Marine Science

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Thalassia hemprichii is a widely distributed and foundation seagrass species in the Indo-Pacific. It inhabits intertidal and subtidal areas along the tropical coast of Western Australia, from the Muiron Islands in the Pilbara to the Kimberley in the north, and is a key food source for green turtles. It is a clonal plant that can grow by producing new leaves and rhizomes but also sexually reproduces. Its seeds are buoyant so it can be dispersed on ocean currents.

This study forms part of the larger WAMSI project on ecological connectivity in the Kimberley marine environment. It aims to improve our understanding of the connection of populations in the Kimberley, provide insight into their resilience and contribute to the design and spatial management of marine assets in the region. We investigated the population connectivity across 16 meadows, 8 in the northern Dampier Peninsular, 5 in the Buccaneer Archipelago and 3 in the Pilbara. In addition we included 2 outgroup populations from Kupang, Indonesia and the Cocos Keeling Islands, Australia. Genetic variability, gene flow and population structure were analysed based on 16 polymorphic microsatellite loci.

Our preliminary results are presented here. There was little evidence of connection between the Pilbara and Kimberley populations, these formed two distinct clusters. Within the Kimberley, there were three significant sub-populations clusters: 1.Bathurst and Irvine Island; 2. Bedford and Riptide Islands; and 3. Northern Dampier Peninsular including the Sunday Island Group and Mermaid Island. There were very low levels of gene flow from sites in the northern Buccaneer Archipelago (Bathurst and Irvine Island) with the other sites. Moderate levels of gene flow were detected from the Bedford Islands to Riptide Islands and the Sunday Island Group, in a predominantly north to south direction. Gene flow was greatest within the Northern Dampier Peninsular, particularly in the Sunday Island group. Not only was there evidence of connectivity through the dispersal of floating seeds (gene flow) but there was also evidence of successful vegetative dispersal in the region. We also found clones (identical individuals = multi locus genotypes) that were shared among populations, separated by tens of kilometres.

WAMSI Research Contacts

Name	Organisation	Email
Azmi, Muhammad	Australian Institute of Marine Science	muhammad.abdulwahab@my.jcu.edu.au
Bayliss, Peter	CSIRO	Peter.Bayliss@csiro.au
Beckley, Lynnath	Murdoch University	L.Beckley@murdoch.edu.au
Bejdar, Lars	Murdoch University	bejder@murdoch.edu.au
Berry, Oliver	CSIRO	oliver.berry@csiro.au
Boschetti, Fabio	CSIRO	Fabio.Boschetti@csiro.au
Bufarale, Giada	Curtin University	giada.bufarale@postgrad.curtin.edu.au
Collins, Lindsay	Curtin University	L.Collins@curtin.edu.au
Crane, Kevin	Office of the Environmental Protection Authority	Kevin.Crane@epa.wa.gov.au
Duckworth, Alan	Australian Institute of Marine Science	a.duckworth@aims.gov.au
Elliot, Bruce	Great Barrier Reef Marine Park Authority	bruce.elliot@gbrmpa.gov.au
Fearns, Peter	Curtin University	P.Fearns@curtin.edu.au
Feng, Ming	CSIRO	Ming.Feng@CSIRO.au
Field, Stuart	Department of Parks and Wildlife	Stuart.field@dpaw.wa.gov.au
Fisher, Rebecca	Australian Institute of Marine Science	r.fisher@aims.gov.au
Gilmour, James	Australian Institute of Marine Science	j.gilmour@aims.gov.au
Gunaratne, Gayan	Department of Parks and Wildlife	gayan.delkanduraarachchige@research.uwa.edu.a
Halford, Andrew	Department of Parks and Wildlife	andrew.halford@dpaw.wa.gov.au
Harvey, Euan	Curtin University	euan.harvey@curtin.edu.au
Hemawan, Udhi	Edith Cowan University	u.hernawan@ecu.edu.au
Heyward, Andrew	Australian Institute of Marine Science	a.heyward@aims.gov.au
Hipsey, Matthew	The University of Western Australia	matt.hipsey@uwa.edu.au
Ivey, Greg	Australian Institute of Marine Science	Greg.Ivey@uwa.edu.au
Jones, Ross	Australian Institute of Marine Science	r.jones@aims.gov.au
Keesing, John	CSIRO	john.keesing@csiro.au

Kendrick, Gary	The University of Western Australia	Gary.Kendrick@uwa.edu.au
Kobryn, Halina	Murdoch University	.H.Kobryn@murdoch.edu.au
Kordi, Moataz	Curtin University	m.kordi@postgrad.curtin.edu.au
Lavery, Paul	Edith Cowan University	p.lavery@ecu.edu.au
Lowe, Ryan	The University of Western Australia	Ryan.Lowe@uwa.edu.au
Masini, Ray	Office of the Environmental Protection Authority	Ray.masini@epa.wa.gov.au
McMahon, Kathryn	Edith Cowan University	k.mcmahon@ecu.edu.au
Mills, Des	Marine Environmental Reviews	desm3@iinet.net.au
Negri, Andrew	Australian Institute of Marine Science	a.negri@aims.gov.au
Pineda, Mari-Carmenh	Australian Institute of Marine Science	m.pineda@aims.gov.au
Revill, Andrew	CSIRO	Andy.Revill@csiro.au
Ricardo, Gerard	Australian Institute of Marine Science	g.ricardo@aims.gov.au
Rogers, Danny	Australasian Wader Studies Group	drogers@melbpc.org.au
Schoepf, Verena	The University of Western Australia	verena.schoepf@uwa.edu.au
Stark, Clair	James Cook University, Townsville	clair.stark@my.jcu.edu.au
Statton, John	The University of Western Australia	John.Statton@uwa.edu.au
Stevens, Alexandra	Curtin University	m.a.stevens@curtin.edu.au
Strehlow, Brian	Australian Institute of Marine Science	Brian.strehlow@research.uwa.edu.au
Sutton, Alicia	Murdoch University	a.sutton@murdoch.edu.au
Symonds, Graham	CSIRO	graham.symonds@csiro.au
Strickland-Munro, Jennifer	Murdoch University	J.Strickland-Munro@murdoch.edu.au
Vanderklift, Mat	CSIRO	Mat.Vanderklift@CSIRO.au
Thums, Michelle	Australian Institute of Marine Science	M.Thums@aims.gov.au
Waples, Kelly	Department of Parks and Wildlife	Kelly.waples@dpaw.wa.gov.au
Webster, Nicole	Australian Institute of Marine Science	n.webster@aims.gov.au
Whinney, James	James Cook University, Townsville	james.whinney@jcu.edu.au
Whiting, Scott	Department of Parks and Wildlife	scott.whiting@dpaw.wa.gov.au