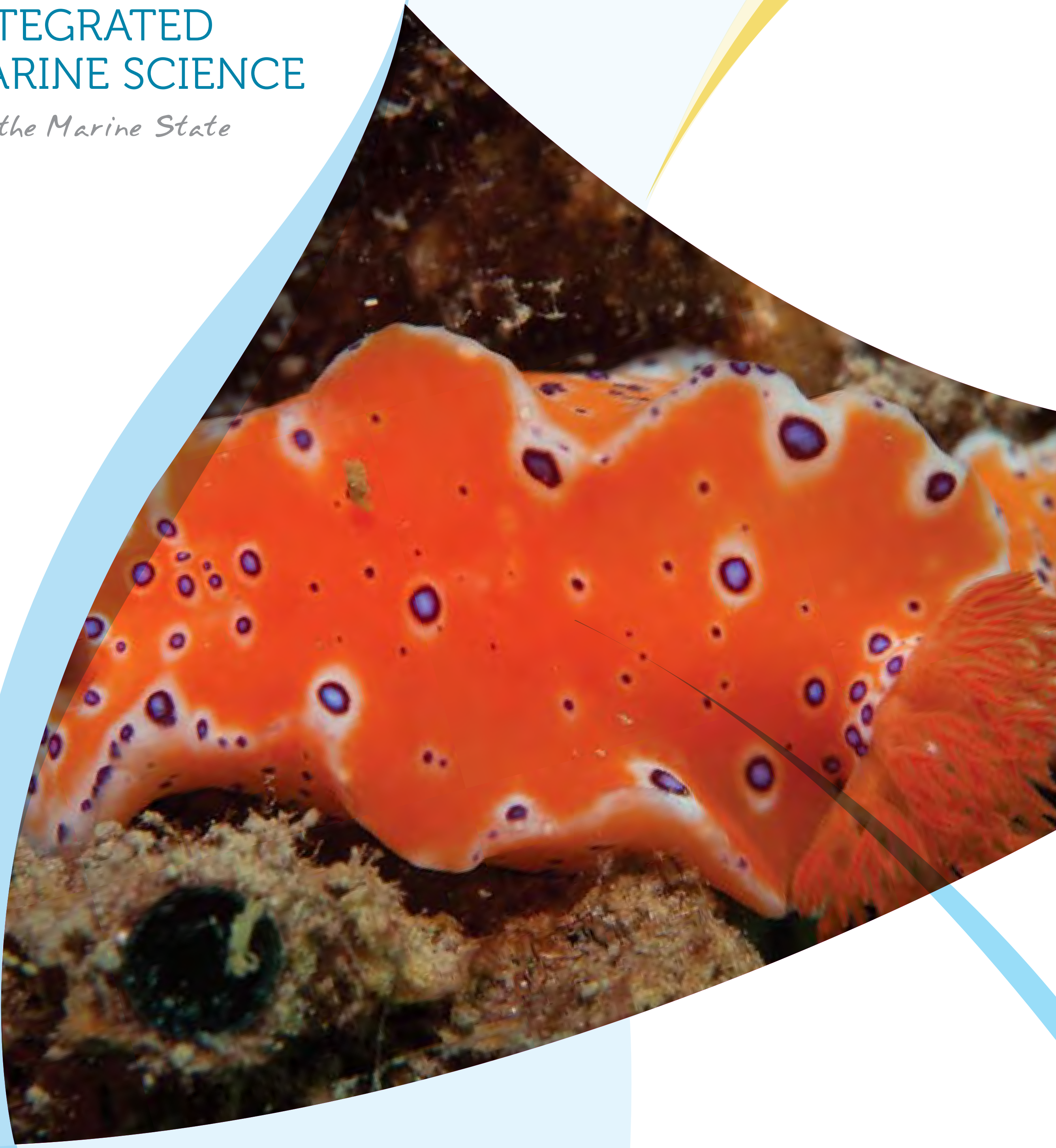
STRATEGIC INTEGRATED MARINE SCIENCE

for the Marine State



NEW KNOWLEDGE
FOR BETTER DECISIONS
AND OUTCOMES

A SYNTHESIS OF
WAMSI RESEARCH
2006-2011

western australian
marine science institution

Strategic Integrated Science for the Marine State

A Synthesis of WAMSI Research 2006-2011

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A full suite of WAMSI publications, including this report and specific research reports is available as a single major reference source from the WAMSI website www.wamsi.org.au

A DVD has been produced containing all the WAMSI 2006-2011 materials which provides a companion to this report.

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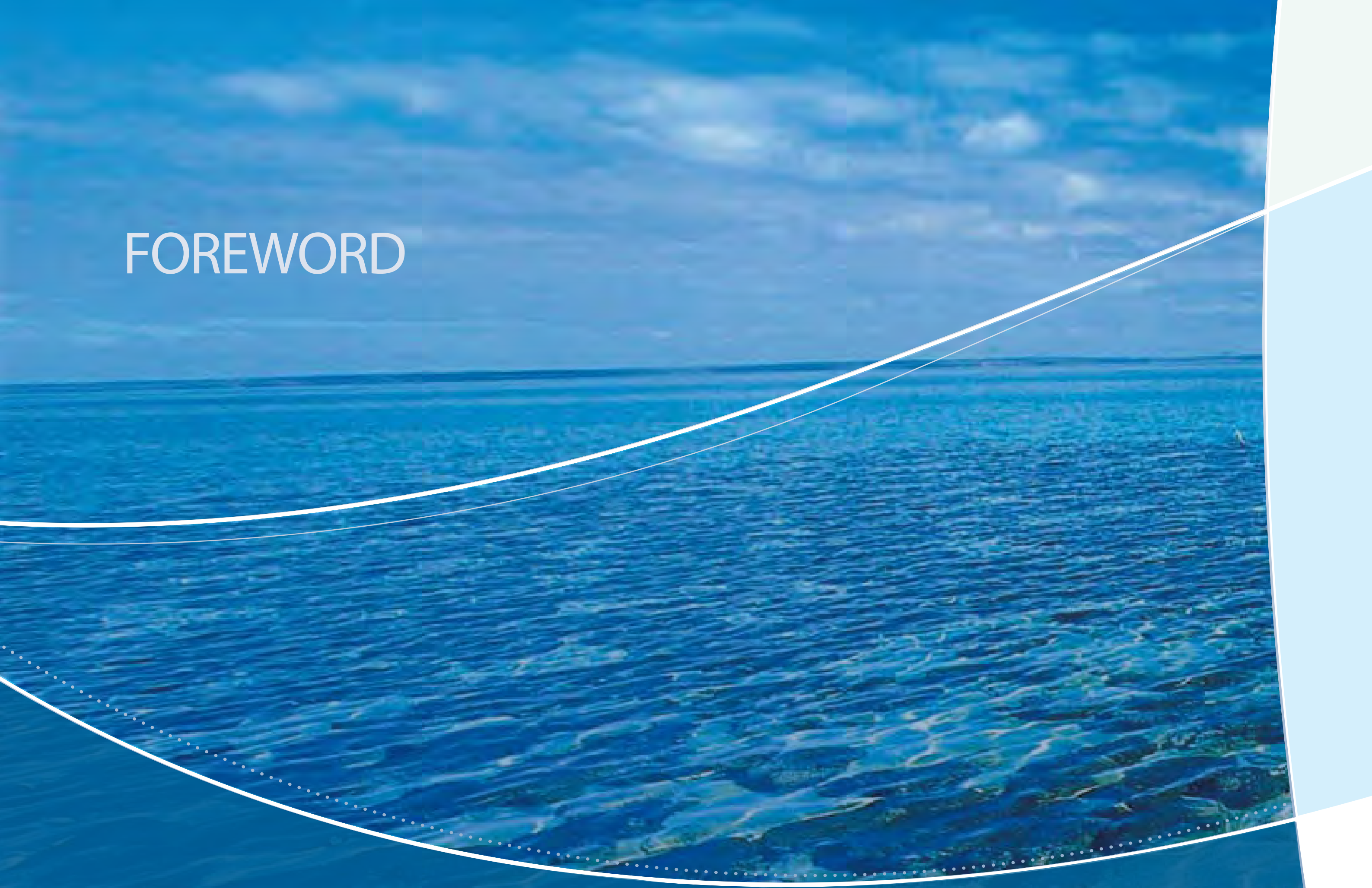


FOREWORD

It gives me much satisfaction to present this report that showcases the key results of the Western Australian Marine Science Institution (WAMSI) research over its first five years, 2006-2011. WAMSI has been a highly successful collaborative institution that has exceeded in meeting its aims and the results speak for themselves.

An ambitious research program has been delivered on time and within budget. The original State Government investment of $21 million has attracted an additional $66.22 million in direct and $5.63 million in indirect funding and in-kind support from both Commonwealth and State Government, and from industry.

WAMSI research over the past five years has made unique new discoveries, strengthened previous knowledge and developed new tools or applied existing national or global models to the Western Australian (WA) context. We have new knowledge and enhanced understanding of the WA marine estate and its biological resources. The roles of oceanic and atmospheric forces in shaping the climate of WA and effects on key fisheries are better known. There has been a 10 fold increase in the knowledge of ecosystem function and process in Ningaloo Marine Park and World Heritage Area. New predictive models and decision support tools have been developed for direct application to specific locations. This knowledge and the new tools will be crucial for management of marine protected areas, fisheries, tourism, marine based industries and coastal development now and in the future.

World class research has improved our understanding of natural climate variability and predictions of longer term climate change for the WA marine environment, particularly as it affects the Leeuwin Current and its influence on the life cycles of key economic and recreational species such as rock lobster.

The South West Bioregion ecosystem and the cycling of nutrients on and off the continental shelf are better understood. This is important for fisheries and marine parks planning and management. We now have a map of the wave climate regime along the South West coast that will assist in coastal infrastructure planning and development e.g. through predictions of coastal inundation under climate change scenarios.

Improved research capacity and coordination has been the hallmark of WAMSI 1 research. The type of research completed would not have been possible through individual research institutions acting independently or through private sector investment. The WA marine science community now has an integrated and coordinated approach to complex research issues to inform management and industry decision-making. There have been immediate benefits from the research, such as the characterisation of deep water internal waves in the Browse Basin area. This knowledge has already been applied to engineering design criteria for underwater pipelines

WAMSI research over the past five years has made unique new discoveries, has strengthened previous knowledge and has developed new tools or applied existing national or global models to the WA context.

and resulted in significant cost savings to industry.

Investment in early career scientists and post-graduate students has improved the marine research capacity of WA now and in the future.

Major policy changes have occurred as a result of WAMSI research. For example, the adoption of Ecosystem Based Fisheries Management as a risk based framework for fisheries management, taking account of wider ecosystem effects, has profoundly changed the way fisheries are managed in WA. The adoption of this policy has been recognised internationally as a world leading innovation.

Data and information collected under WAMSI programs will now be available for future researchers, through innovative data management systems adopted by WAMSI.

WA has Australia's longest coastline and an internationally significant coastal and fishing zone that contains temperate and tropical ecosystems on the continental shelf and in deep water. There are still significant gaps in the knowledge needed to address the State Government's high level policy objectives for marine science, marine conservation and marine natural resource management. There is still much to be done.

Enhanced predictive capacity on the likely effects and consequences of climate change needs to be built. Downscaling global and national climate models to specific WA locations is a key component of this research. Better predictive understanding is needed of the cumulative impacts of development and usage on the coastal and marine environment of Western Australia.

Further research into iconic marine wildlife is needed to ensure protection and meet public expectations.

The Kimberley marine environment is still largely unknown and urgent work is needed to characterise that environment and its values, in order to manage the impacts of large scale developments, while protecting the unique environment. This will form a new research program under WAMSI 2 to commence in 2012.

Likewise, understanding the effects of dredging on marine environments is an urgent requirement and this has also been recognised through the establishment of a new Dredging Science Program to commence in 2012.

The past five years has been a challenging and exciting time in WA's development, and WAMSI has played a major role in generating relevant and timely information for management and decision making. The collaborative research culture and marine science capacity that has been built is an excellent base for further work in support of the State's development.

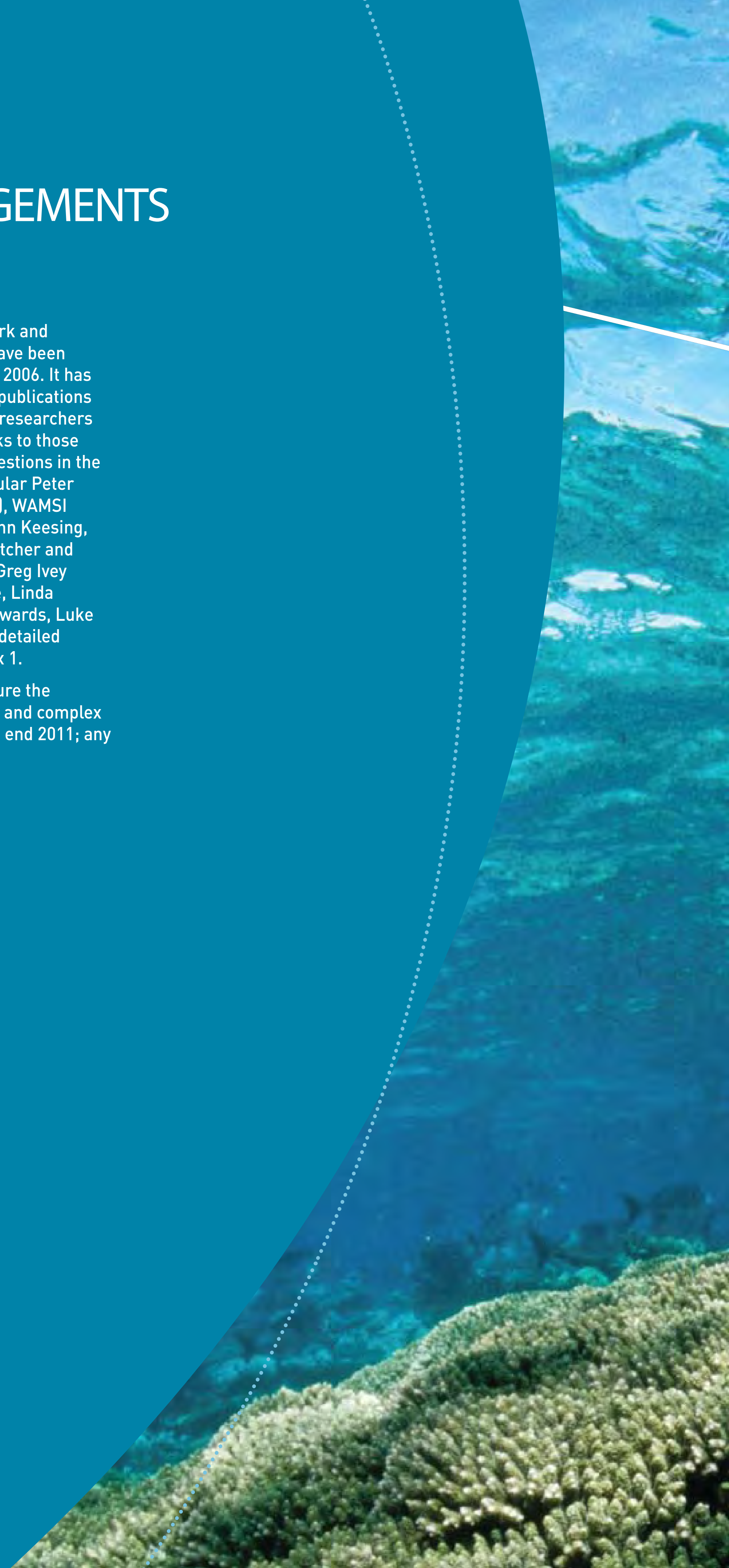
I take this opportunity to acknowledge the excellent work of the WAMSI Governors, Board members, Committee members, executive group and the numerous scientists and students whose hard work and commitment has produced the outcomes highlighted in this report. I commend the report to readers.

Peter Rogers
Independent Chairperson
WAMSI Board

ACKNOWLEDGEMENTS

This report is based on the hard work and commitment of many people who have been part of WAMSI since its inception in 2006. It has been compiled from the numerous publications and reports generated by WAMSI 1 researchers over the past five years. Many thanks to those who contributed material and suggestions in the compilation of this report, in particular Peter Rogers (WAMSI Board Chairperson), WAMSI Board members, Node Leaders (John Keesing, Ming Feng, Chris Simpson, Rick Fletcher and Dan Gaughan, Howard Shawcross, Greg Ivey and Chari Pattiaratchi), Steve Blake, Linda McGowan, Michael D'Silva, Luke Edwards, Luke Smith and Stan Stroud. For a more detailed acknowledgement list see Appendix 1.

Every effort has been made to capture the important outcomes of this exciting and complex initiative over the period mid 2006 - end 2011; any errors are those of the author.



EXECUTIVE SUMMARY

In mid 2006 the Western Australian Government committed $21 million over five years to the establishment of the Western Australian Marine Science Institution (WAMSI), as a State Major Research Facility (MRF). This investment has been returned handsomely by attracting another $71.85 million in cash and in-kind support that has delivered immediate benefits to WA and that will continue to deliver benefits into the future. The State Government's high level policy objectives for marine science, marine conservation and marine natural resource management, including strategic marine science capability and consequences and impacts of climate change, have all been addressed through integrated, collaborative, high quality research.

The overall result has been a fundamental improvement in the understanding of the marine environment of WA and its values, and new knowledge for sustainable management of the WA marine estate. This is timely given unprecedented economic growth driven by mining and offshore oil and gas industries, particularly in the last 10 years, increasing human use pressures on marine resources and uncertainty from climate variability and climate change.

WAMSI set out with a major strategic objective to "strengthen the coordination and capacity of marine research in Western Australia and to enhance the transfer of research outputs into outcomes of economic, environmental and social benefit to Western Australia." WAMSI has achieved this strategic objective to a high degree through the following target outcomes:

Improved coordination of marine science activities in Western Australia

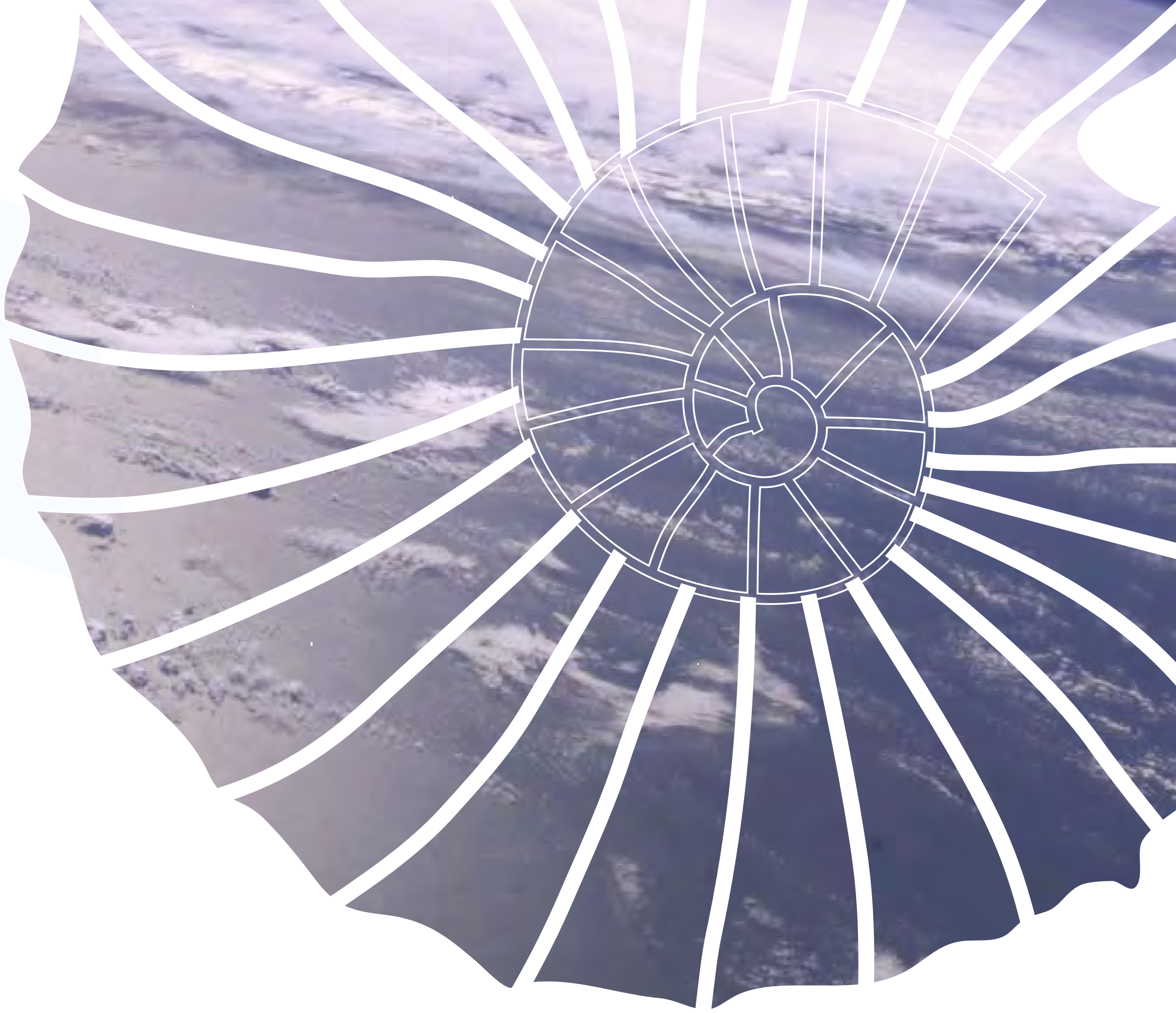
A strong collaborative and cooperative marine research community has been built in WA over the past five years. Following the establishment of WAMSI in 2006, CSIRO relocated its Wealth from Oceans Flagship to Perth and the Australian Institute of Marine Science (AIMS) significantly increased its marine research capability in WA. Research "social capital" has been built through new networks of collaborative researchers across different disciplines and from a range of government agencies, research institutions and private sector companies. Additional marine research capacity has been generated through support for 34 post-graduate students and through the application of the skills of the partner institutions to the WA marine context. This has had a flow-on effect to government, the resource sector and the burgeoning marine consulting industry in WA.

Improved understanding of the marine and estuarine ecosystems of Western Australia

There has been a fundamental improvement in knowledge about the WA marine estate (Fig 1), particularly Ningaloo Marine Park and World Heritage Area, the physical and biological processes that have produced such a valued place and its current condition and trends. This new knowledge has validated the strategies, assumptions and objectives built into the 2005 Ningaloo Marine Park Management Plan. The identity of the WA marine environment as a global biodiversity 'hotspot' has been further confirmed with the exploration of new deep water habitats and the discovery of many new species of sponges.

WAMSI researchers were early adopters of Integrated Marine Observing Systems (IMOS) data streams as a basis for much of WAMSI oceanographic and engineering research. The value of these combined data sets was demonstrated in the rapid analysis and explanation of the 'marine heatwave' that bleached coral reefs and killed large numbers of fish off the WA coast in February 2011.

Research in the South West bioregion has added to understanding of key fisheries (e.g. western rock lobster, demersal scale fish) and their role in marine ecosystems.



The importance of sediments and key structuring species such as kelp in benthic primary production and the cycling of nutrients (critical to healthy ecosystems and fish communities) are now much better understood. Photosynthetic deepwater temperate sponges off the continental shelf have been discovered for the first time.

Important baseline research has been done in the Kimberley region to characterise benthic habitats, in advance of the decision on the location of the Kimberley Gas Hub precinct. Valuable research has been undertaken with industry funding on whale migration paths along the WA coast and into the Kimberley.

Enhanced predictive capacity to model both natural and anthropogenic effects

WAMSI research has generated a better understanding of the complex forces that influence the climate of WA and the variability in key oceanographic processes such as the Leeuwin Current, over different spatial and temporal scales. This understanding is essential for the management of fisheries, ports, coastal planning and marine parks in the face of climate change. This research has in turn made a valuable contribution to the validation and development of national climate models.

Coastal maps and predictions about wind wave regimes, sea level changes and storm surges have been developed. These will be important for coastal planning decisions about the vulnerability of current and future coastal infrastructure to inundation and erosion, such as in the Peel-Harvey Inlet.

Downscaled hydrodynamic and biogeochemical models that can be applied at scales of metres rather than kilometres have been developed initially for the South West Bioregion but can be applied to any part of the WA coast.

World-class survey methods for understanding the motivations and patterns of recreational fishing in WA have been developed. These will improve the capacity to manage the effects and enjoyment of recreational fishing and ensure sustainable fishing for the future.

Better decision support tools have been developed to improve forecasting and scenario modelling to deal with potential changes in the natural and human environment, e.g. the Management Strategy Evaluation model applied to Ningaloo Marine Park will allow complex future management scenarios to be evaluated; the Tourism Destination Model for Ningaloo Coast will be used by DEC and the Exmouth Shire to improve the planning for tourism use of both the terrestrial and marine environments.

Improved understanding of the physical forces, such as internal waves that impact on the seabed in deep water off the North West Shelf has already been applied by the oil and gas industry to offshore infrastructure design. Design criteria for subsea gas pipeline construction have been modified thereby reducing risk of failure and increasing efficiency and reducing costs.

Improved management decisions based on the outputs of the WAMSI research

The capacity to manage the WA marine estate and fisheries has been enhanced significantly through WAMSI research. The adoption of Ecosystem Based Fisheries Management (EBFM) will change fundamentally the way in which fisheries and ecosystems are managed in WA. This management policy moves from a fishery-by-fishery approach to an ecosystem-wide approach. Risk assessment tools are used to identify high priority fisheries issues while also considering ecological, social and economic factors in resource allocation decisions.

The wealth of additional knowledge gained about the functioning of key marine reserves (Marmion Marine Park, Rottnest Island Marine Reserve and Ningaloo Marine Park, in particular) will enhance decision-making and management planning in the future. Better understanding of climate variability and the likely effects of climate change on WA marine ecosystems and coastline will be an invaluable aid in coastal and marine management for ports, oil and gas industry, shipping, coastal infrastructure management and water quality management.

Guaranteed ongoing investment in the Institution and the value recognised by the State

Over the past five years the original State Government MRF grant of $21 million has been leveraged to a total of $92.85 million in cash and in-kind support, including an additional $5.63 million in commissioned projects (e.g. Kimberley coastal benthic surveys, humpback whale migration research). WAMSI research projects have also generated additional direct grants to partners (e.g. additional Fisheries Research and Development Corporation (FRDC) grants totalling $0.567 million to add to WAMSI fisheries-related projects). WAMSI has been a significant catalyst in attracting complementary projects (e.g. the Ningaloo Atlas funded by BHP-Billiton and managed through AIMS; Commonwealth funding for the new Indian Ocean Marine Research Centre (IOMRC). Partnership in WAMSI gave greater certainty to CSIRO co-investment opportunities, and the associated need for senior leadership based locally in Perth. As a consequence, CSIRO relocated the headquarters of the Wealth from Oceans Flagship (Australia's largest marine science organisational capability) from Sydney to Perth in 2009. This ability to generate further investment to value-add to core funding is a good indicator of future success in attracting further collaborative funding from industry and granting bodies.

The State Government has already recognised the value of WAMSI research 2006-2011 in furthering State Government priorities, by the provision of additional funding for new areas of research in Strategic Dredging Science and Kimberley Marine Science.

Other significant additional outcomes:

WAMSI funding was a catalyst for new State legislation that will give certainty to investment in marine biodiscovery and biotechnology. This legislation should encourage research based on WA's unique marine life into novel molecules and bacteria for possible pharmaceutical, agricultural and other applications. The funding also supported the establishment of the WA Marine Biological Resources Library (WAMBL) at the WA Museum to manage the identification, curation and release of marine specimens for research.

A key legacy of WAMSI 2006-2011 is improved data management and efficiency. All WAMSI generated data is to be available in the public domain, lodged either with the agency data centre or with iVEC and made available to other researchers via on-line discoverability and access methods. The establishment of the WA Node of the Australian Oceans Data Network [AODN] was a direct response to the improved data management systems adopted by WAMSI.

The quality of the research and researchers engaged in WAMSI research has been recognised by the establishment of science linkages between international experts and several WAMSI scientists e.g. in deepwater sponge identification, ocean engineering applications, and understanding the predicted effects of climate change in the Indian Ocean.

WAMSI support for 34 early career scientists has enhanced marine science capability and capacity in WA. These researchers have been exposed to the research needs of industry and government and will form a powerful cohort of marine science capacity, much of which will remain in WA.

Summary

In conclusion, WAMSI is an excellent model for governance and coordination of collaborative, effective and efficient delivery of research outcomes for government and industry. The original State Government investment has leveraged multiple additional grants and investment. The research has been cost-effective and transparent and the legacy will endure for many years, particularly through the “research social capital” and enhanced marine science capability that has been generated. Further benefits will accrue from the repositories of specimens and data and the development of new analytical and predictive tools.

WAMSI research over the period 2006-2011 has delivered top quality information addressing key issues of relevance to government, industry and community that should enhance the efficiency and effectiveness of decision making in both the short and longer term. WAMSI research data and information are already being applied to improved decision making in government and industry.

The type of strategic, integrated research undertaken through WAMSI as a coordinating institution would not have been achieved through normal market forces or private sector research and development. There have been beneficial outcomes of the research immediately to State Government agencies as well as industry and further benefits will continue to flow to industry, government and community for many years to come. It is only through organisations like WAMSI that the complex State and national strategic marine science priorities can be addressed effectively and efficiently.

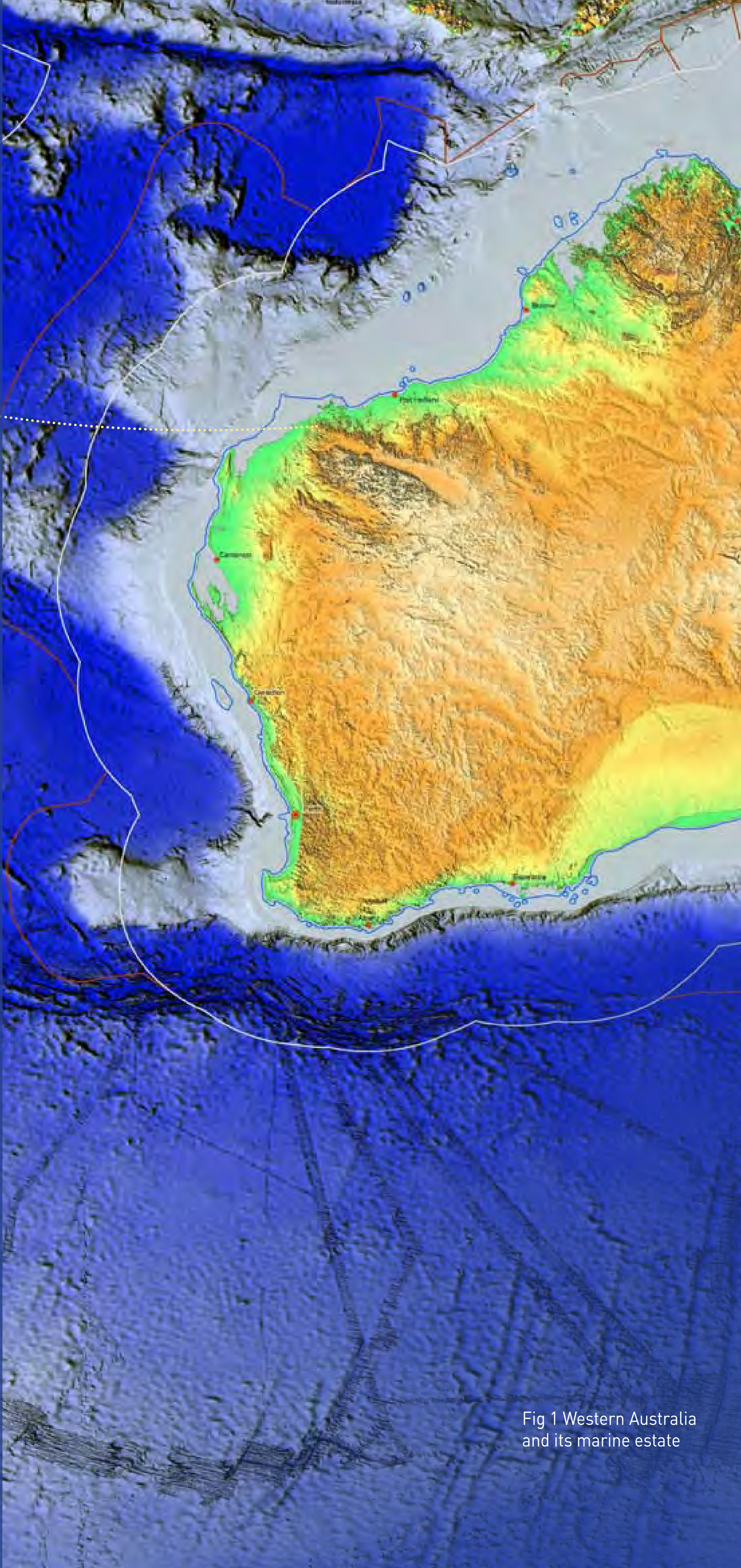


Fig 1 Western Australia and its marine estate

1.

INTRODUCTION AND CONTEXT

In mid 2006, the State Government committed $21m over five years to the establishment of the Western Australian Marine Science Institution (WAMSI). An earlier program, the Strategic Research Program for the Marine Environment (SRFME), established as a six year $20 million joint venture between CSIRO and the State Government, had made significant progress in addressing strategic research information needs, but was concluding in 2006. It had become clear that the strategic marine science needs of WA would best be met through government investment in a strategic research program managed by an independent institution that provided integration across different research providers and disciplines for the benefit of multiple stakeholders.

Addressing the State Government's high level policy objectives for marine science, marine conservation and marine natural resource management, was a key component of the decision in July 2005 to establish and fund WAMSI as a Major Research Facility (MRF) as part of a competitive process with other research needs.
These objectives were:

- Science needs for implementation of Integrated Fisheries Management and Ecosystem Based Management of Fisheries;
- Marine Conservation Reserves (in particular through the Ningaloo Research Program);
- Strategic marine science capability; and
- Consequences and impacts of climate change.

Some of the challenges and drivers for this initiative came from the demand for information to support government environmental and related decision making in natural resource management, environmental impact assessment and marine conservation. This need for information has become more acute given the recent rapid development of the offshore oil and gas industry. Much of the WA marine estate is in deepwater and remains poorly surveyed and explored.

Fisheries management required a new approach to go beyond fishery-by-fishery level management to consider cumulative effects of fisheries in a regional context. Ningaloo Marine Park had been rezoned in 2004 amid contentious public debate and with an extensive commitment to research and monitoring to assess the assumptions contained in the plan and measure the effects of human use and other impacts.

Better information was needed to assess the increasing effects of climate variability and change (e.g. predicted increases in the intensity of tropical storms, rising sea levels, rising sea and atmospheric temperatures) on ecosystems, fisheries, marine protected areas and coastal infrastructure. The potential for biodiscovery and biotechnology from the unique marine environment of WA was not being realised. It was clear that better information systems and predictive/planning tools were needed in order to manage responsibly coastal and marine use and development for economic and social benefit, while maintaining high quality public good environmental assets.

These broad needs drove the establishment of the key science questions to be addressed by six inter-related nodes of research coordinated through WAMSI. Additional funding was provided in 2011 to establish two new research Nodes. The first Node will address dredging science. New ports are rapidly being built in the northwest, including significant dredging in potentially sensitive areas, to provide infrastructure for the export of minerals and LNG. Better knowledge is needed to assist government and industry in the management of dredging impacts. The second Node will undertake research in the Kimberley marine environment in support of the State's Kimberley Science and Conservation Strategy.

Some key questions posed at the outset of WAMSI included:

1	What is the extent and diversity of the unique marine estate of WA and how is it characterised, particularly deep water communities? What are the sources of nutrients that sustain productive benthic ecosystems and their high levels of biodiversity? What role do waves play in structuring marine habitats? Will the development of important industries offshore jeopardise the conservation and natural resource values of the marine estate?
2	Ningaloo Marine Park was established based on best available knowledge. Is the 2005 zoning plan appropriate? What changes in use and perceptions will occur? How will key species be affected? Is the size and location of the sanctuary zones appropriate and are there any unforeseen consequences from changes in use patterns? What are the likely effects of climate change on the management of marine protected areas and marine reserves?
3	What are the forces that bear on fixed and floating structures on the shelf and in deep water? What are the potential risks from development activities e.g. dredging operations, drilling platforms and other infrastructure in the marine environment and how might those risks be managed efficiently and effectively? What information is needed to improve safety, reliability and economy in the design and operation of offshore oil and gas platforms and pipelines?
4	What are the potential effects of climate change on the coast of WA on oceanographic processes, Leeuwin Current, weather patterns, key fisheries, sea levels and wind wave regimes. How resilient are high value marine habitats and species in the face of climate change?
5	How can fisheries management be improved, taking into account wider ecological, social and economic issues? What are the effects on non-target species and the broader ecosystem from commercial and recreational fisheries? What are the likely effects of climate change on key fisheries?
6	Are there undiscovered natural resources in the marine estate that might need further protection or be the sources of new industries?

This report is primarily concerned with research undertaken by the six foundation research Nodes (Table 2).

Marine Environment of Western Australia

Western Australia's coastline is approximately 27,000 km long and contains a range of climatic zones, from temperate on the south and lower west coast, through tropical semi-arid on the north west coast to monsoonal in the north. Tides range from less than 1 m in the south to over 11 m in the north.

Coastal waters on the south and west coast are generally nutrient poor and very clear whereas inshore waters along the northwest and northern coast contain higher suspended sediment loads and are more turbid. The Leeuwin Current flows southward along the continental shelf break, stronger in winter than summer, maintaining relatively high seawater temperatures and providing a mechanism to transport tropical species into temperate waters. The current also prevents significant 'upwelling' of nutrient-rich waters from the deep ocean on the scale of those that sustain the highly productive anchovy/sardine fisheries off the west coasts of South America and South Africa. This physical setting has produced a wide variety of ecosystem types with many unique features. For example:

- Ningaloo Reef – a 270 km long fringing coral reef less than 6 km offshore;
- Inverse estuarine ecosystem maintained by 20,000 km^2 of seagrass meadows at Shark Bay;
- Extensive arid-zone mangrove communities along the Pilbara coast;
- Extensive high latitude coral reef complex at the Abrolhos Islands;
- Nutrient-poor coastal lagoons and embayments protected by limestone reefs and characterised by highly diverse and endemic seagrass flora along the central west and south coasts;
- Nutrient-poor high-energy coast with granite reefs and cliffs and highly diverse and endemic floral and faunal assemblages along the lower west and south coasts;
- Unique inshore algal and coralline reef structures and embayments along the Kimberley Coast; and
- Unique deep-water communities off the continental shelf edge.

The marine biodiversity of Western Australia is exceptionally rich with the area from North West Cape to Perth recognised as one of the world's eighteen marine biodiversity 'hotspots'. For marine endemism it is ranked second in the world. Recognition of the unique costal environment has occurred through the listing of Shark Bay and the Ningaloo Coast as world heritage sites as well as the 2011 listing of the West Kimberley region on the National Heritage Register.

(adapted from The WA State Sustainability Strategy 2003)

Fig 2

WAMSI Partners

State Government

Department of Environment and Conservation
Department of Fisheries
Department of Commerce
ChemCentre
WA Museum
Office of the EPA (included in 2011)

Commonwealth Government

CSIRO (Wealth from Oceans Flagship)
Australian Institute of Marine Science
Bureau of Meteorology

Universities

University of Western Australia
Curtin University of Technology
Murdoch University
Edith Cowan University

Industry Collaborators

Woodside Energy Ltd

BHP – Billiton (2006-2010)

Other

WAGOOS

Governance and Operations

WAMSI is an unincorporated joint venture of partner organisations and industry collaborators (Fig 2). The structure (Fig 3) includes at the highest level a set of Governors, representing the partners, with a subset of that group comprising the Governing Board for broad strategic oversight of the program and operations. In that way, responsibility for implementation of the business plan, for efficient and integrated conduct of the research, and for achieving outcomes rests with the eight member Governing Board of senior executive level representatives and an independent Chairperson. Executive support and all day-to-day operations, extension, finances and program development are managed by a small Secretariat headed by the CEO. Research in the period 2006-2011 was undertaken within and between six foundation Research Nodes headed by Research Node Leaders nominated by the Parties (Table 1). A seventh Node in strategic dredging science was added in 2011. Five Board Committees and two operational groups provide for coordination, audit, review and advice to the Board as well as a specific focus on collaboration and communication:

1. Strategic Programs Committee
2. Research and Development Committee
3. Audit and Finance Committee
4. Dredging Science Advisory Committee
5. Review Committee
6. Operations Group
7. Communications Group

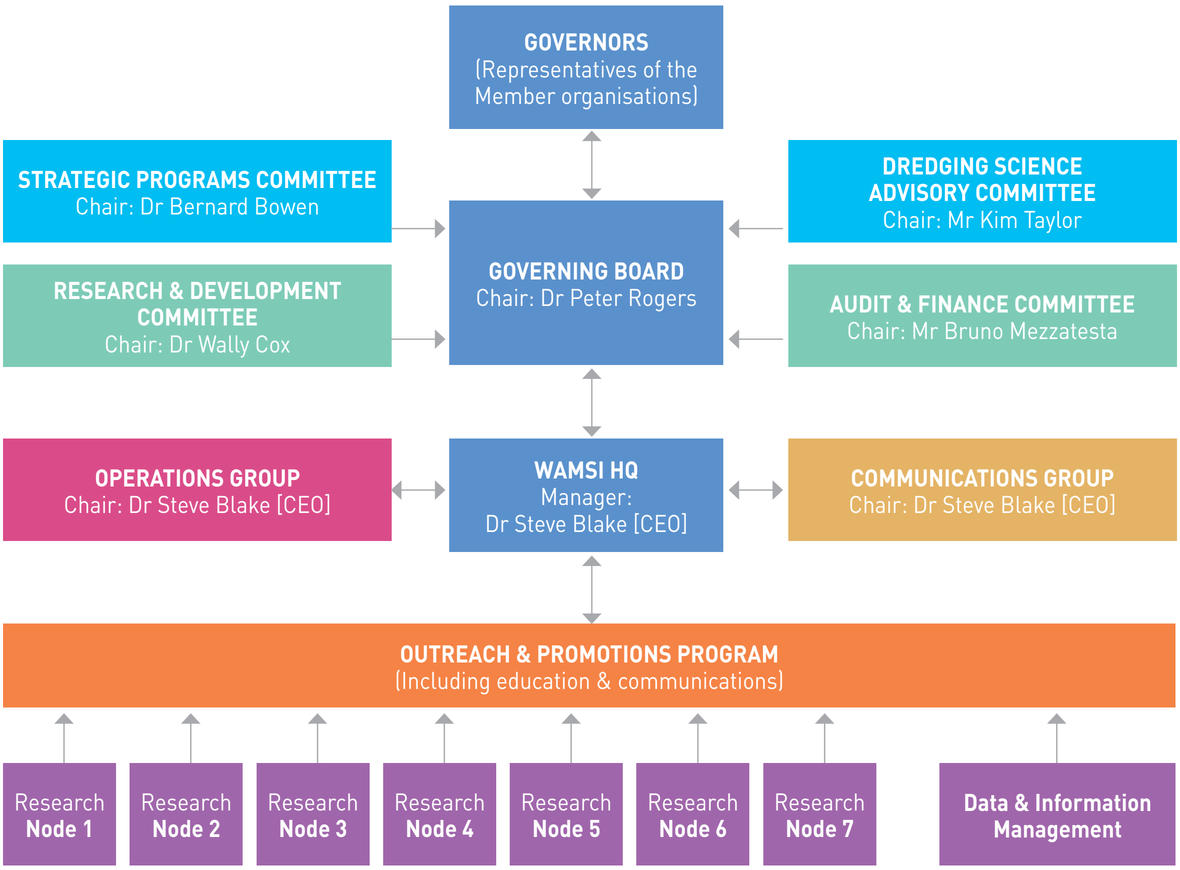


Fig 3 WAMSI Governance and Operations

The Board approves all research programs and projects. A rigorous system of reporting and accountability is embedded in the research agreements. Quality control is maintained through the Research and Development Committee, internal processes of the research providers, through periodic reviews of Node research results and through rigorous and well-established peer review processes for publication in scientific journals.

Project design requires all projects to be multi-institutional and multi-disciplinary research thus fostering collaboration and joint publications, a hallmark of WAMSI over the last five years.

Post-graduate students, post-doctoral Fellows or established researchers have undertaken much of the key research within the six foundation Nodes. These students and Fellows have added significantly to the capacity of marine research in WA and the benefits of this investment will continue for many years through their continued employment in the marine science sector.

WAMSI has undertaken significant communication activities over the past five years. Conferences and integrated research symposia within and between nodes (37 in total) have ensured that research progress is reported and discussed publically. Other activities have included the production and dissemination of brochures, fact sheets, documentaries, and public information events as well as maintaining a current and up to date website www.wamsi.org.au. The WAMSI Communication Group is made up of the Communication Managers from each of the partner agencies to ensure broader benefits and opportunities are realised, especially the integration of the WAMSI Node 3 research with the CSIRO Wealth from Oceans Flagship Ningaloo Cluster.

2.

RESEARCH OVERVIEW

WAMSI research has been driven by the information needs first identified by end-users in government, industry and community and included in the initial MRF proposal to government in 2005. The research program has been set in the broad context of strategic policy priorities for WA established by government such as sustainable resource management, understanding climate variability and the likely effects of climate change, management of ocean ecosystems, marine parks and fisheries, biodiversity conservation and capacity building. The strategic research needs were developed through a collaborative process that addressed high-level management needs for the State, including those for improving natural resource management more broadly and explicitly to underpin opportunities for progress of the resource sector, infrastructure development, understanding of potential climate change impacts and biodiscovery in the context of conserving the marine estate.

The WAMSI model demanded a collaborative approach to ensure the best integration of corporate knowledge relevant to the management questions being addressed, but also to both foster stronger links across institutions and to build new capacity across a range of disciplines.

Research Design

Three integrating science themes were adopted to guide the establishment of the initial research programs:

1. Oceans Systems Forecasting
2. Biodiversity Conservation
3. Natural Resource Management

The research approach taken was to identify those primary areas of knowledge that were needed in order to deal with the emerging management issues and challenges from existing industries (e.g. commercial and recreational fisheries), fast growing resource sectors (e.g. offshore oil and gas industry, iron ore and mineral export, major infrastructure development such as ports) and the responsibilities for understanding, managing and conserving the marine estate. Research was then delivered through projects within 6 Research Nodes, headed by senior researchers from partner research providers (Table 1).

Node	Research Program	Research Leaders
1	Marine Ecosystem Science	Dr John Keesing, CSIRO (2006 - 2011)
2	Climate Processes, Predictability and Impacts	Dr Ming Feng, CSIRO (2008 – 2011) Dr Bryson Bates, CSIRO (2007 – 2008) Dr Gary Meyers, CSIRO (2006 – 2007)
3	Conserving Marine Biodiversity	Dr Chris Simpson, WA Dept of Environment & Conservation (2006 – 2011)
4	Sustainable Marine Ecosystems	Dr Rick Fletcher, WA Dept of Fisheries (2006 – 2011)
5	Biodiversity, Biotechnology and Aquaculture	Mr Howard Shawcross, WA Dept of Commerce (2011) Mr Jason Froud, WA Dept of Fisheries (2009 – 2011) Ms Fiona Vom Berg, WA Dept of Fisheries (2008 – 2009) Dr Chris Battershill, AIMS (2006 – 2008)
6	Ocean Predictions for Offshore and Coastal Industry	Prof Greg Ivey UWA (2006 – 2011) Prof Chari Pattiaratchi UWA [Deputy-Node Leader] (2006 – 2011)

Table 1

A seventh Node on Strategic Dredging Science was added in 2011 (see Section 4.5).

For more details of Node objectives and projects see WAMSI website www.wamsi.org.au

3.

STAKEHOLDER VIEWS

The governance model adopted by WAMSI has been consistent with best-practice corporate governance and has been effective in setting the strategic direction and maintaining focus on "big-picture" outcomes relevant to the strategic directions and key management questions. All WAMSI partners are represented at Board level and, as appropriate, on expert or operational committees. The governance of WAMSI has been characterised by goodwill and a clear intent to maximise the opportunities for integration and collaboration. The small secretariat has been effective in coordination and delivery of research programs, while the research provider institutions responsible for science leadership have delivered excellent results on time and within budget.

Key stakeholders have endorsed the success of WAMSI governance processes and its integrating role in marine research. The following selection of endorsements illustrate stakeholder support:

"As Chief Scientist of Western Australia, I see the key importance of Government, the commercial world and academe working together. You need all three for the most positive approach and the best outcome. I would consider WAMSI to be an excellent example of such collaboration. The outcome-driven approach, incorporating such leading organisations as Australian Institute of Marine Science and CSIRO, has generated valuable outcomes for our State and beyond economically and socially. In addition, WAMSI has played an important role in training the next generation of marine biologists and oceanographers, crucial skill sets as we seek to understand better our oceans and the Indian Ocean in particular."

Professor Lyn Beazley AO FTSE, WA Chief Scientist.

"The willingness of all parties to bring their research capacity to the table and have it integrated with other research capacity is an essential requirement (for success)…. WAMSI has provided an integrating influence that has encouraged national research providers such as AIMS and CSIRO to take a significant role in Western Australian marine research issues. WAMSI stands out as a governance model for integrating marine research"

Dr Bernard Bowen AM FTSE, WAMSI Foundation Chairman.

Many researchers and other stakeholders have endorsed the importance of discovery and understanding of the unique biodiversity of WA's marine estate, much of it endemic to this part of the world. Identifying the distribution and abundance of species, the range of key habitats and the complexity of communities allows for better judgments about managing human uses and impacts as well as potential new benefits from discoveries.

"We now have new tools, technologies (and) genetics that were not available even 10 years ago to look at marine life. It is exciting to have the opportunity of the wonder of discovery and to characterise that part of the planet that is still largely unknown"

Dr Tom Hatton PSM, Director CSIRO Wealth from Oceans Flagship.

"WA has a wealth of biodiversity. The discovery element of WAMSI is an important feature. For instance deepwater sponge communities found off Ningaloo Marine Park are exceptionally rich and diverse, with many new species that could play important roles in the communities and give new insights into how they respond to impacts"

Dr Jamie Oliver, Science Leader, AIMS, Western Australia.

"Many deepwater species have developed special chemical adaptations in order to survive and live in harsh environments. Biodiscovery research is important for drugs for humans e.g. anti-bacterial, anti-viral and anti-cancer agents found in the natural environment. Chemists screen for compounds in plants and animals that have evolved unique defence systems, then synthesise these compounds in labs. We need to keep looking because bacteria keep evolving and new drugs are needed".

Dr Jane Fromont, Head of Department and Curator of Marine Invertebrates, Western Australian Museum.

"Many of the ecological and physical processes that shape the marine environment happen over a range of time scales from days to decades, and over large spatial scales. WAMSI is able to undertake big-picture studies over long time-scales to understand these processes. Findings from these studies support the ongoing sustainable development of this State."

Dr Luke Smith, Principal Environmental Scientist, Woodside.

Ningaloo Marine Park was a core component of the research program that sought to understand better the natural characteristics of this iconic place and to validate the planning decisions made in the establishment of Ningaloo Marine Park.

"The global significance of Ningaloo is only just starting to be appreciated because of the intense effort from WAMSI over the past five years. The focus on Ningaloo is very important. The Ningaloo experience is great for people who like the ocean – its remoteness, pristine areas, lots of wildlife, clear waters, catching fish, sunsets etc. We needed to test sanctuary zones in deepwater – are they in the right place and protecting appropriate representative assemblages of plants and animals? WAMSI research has confirmed that our planning decisions were right. Not only that but we found very high levels of biodiversity and new deepwater species of sponges."

Dr Chris Simpson, Program Leader, Marine Science Program, Department of Environment and Conservation, WA.

Building capacity in marine science in WA was an important objective of WAMSI research. 34 PhD students were supported by WAMSI and many of these have moved into employment in both small and larger firms in WA. The following industry perspective illustrates the value of capacity building:

"An important component of WAMSI is to build marine science capacity and capability in the State, whether physical or ecological expertise. We see that WAMSI plays a really important role in building that capacity and capability of scientists and environmental professionals to meet the challenges of marine management and impact assessment in WA."

Dr Luke Smith, Principal Environmental Scientist, Woodside.

The building of a collaborative culture between research providers and with research end-users has been very successful. The "social capital" of trust, synergies and networks developed in the research community has been of immense benefit over the past five years and will continue to be of benefit in years to come. Some comments from researchers and end-users illustrate this outcome.

"We have distinct needs for sustainable development of our business, and some of those are best met through partners such as WAMSI. Through WAMSI, Woodside was able to partner with the Australian Antarctic Division to satellite tag humpback whales in the Kimberley, which lead to a better understanding of their annual migratory pathways. This research is an example of how, though WAMSI, we can link with the best scientists in WA and Australia to get outcomes that serve both conservation management and the environmental impact assessment process."

Dr Luke Smith, Principal Environmental Scientist, Woodside.

"WAMSI projects have been highly collaborative at both institutional management level down to the level of individual scientists. AIMS projects have all been strongly collaborative, sharing data, methods and techniques as well as ship time. WA universities, CSIRO and government agencies have all been involved. The AIMS research vessel RV Solander often hosts up to 12 scientists from 2-3 institutions at any one time."

Dr Andrew Heyward, Principal Research Scientist, AIMS.

"From a national perspective, the opportunities to grow marine science are greatest in WA. Partnership in WAMSI gave greater certainty to CSIRO co-investment opportunities, and the associated need for senior leadership based locally in Perth. As a consequence, CSIRO relocated the headquarters of the Wealth from Oceans Flagship (Australia's largest marine science organisational capability) from Sydney to Perth in 2009."

Dr Tom Hatton, Director, CSIRO Wealth from Oceans Flagship.

4.

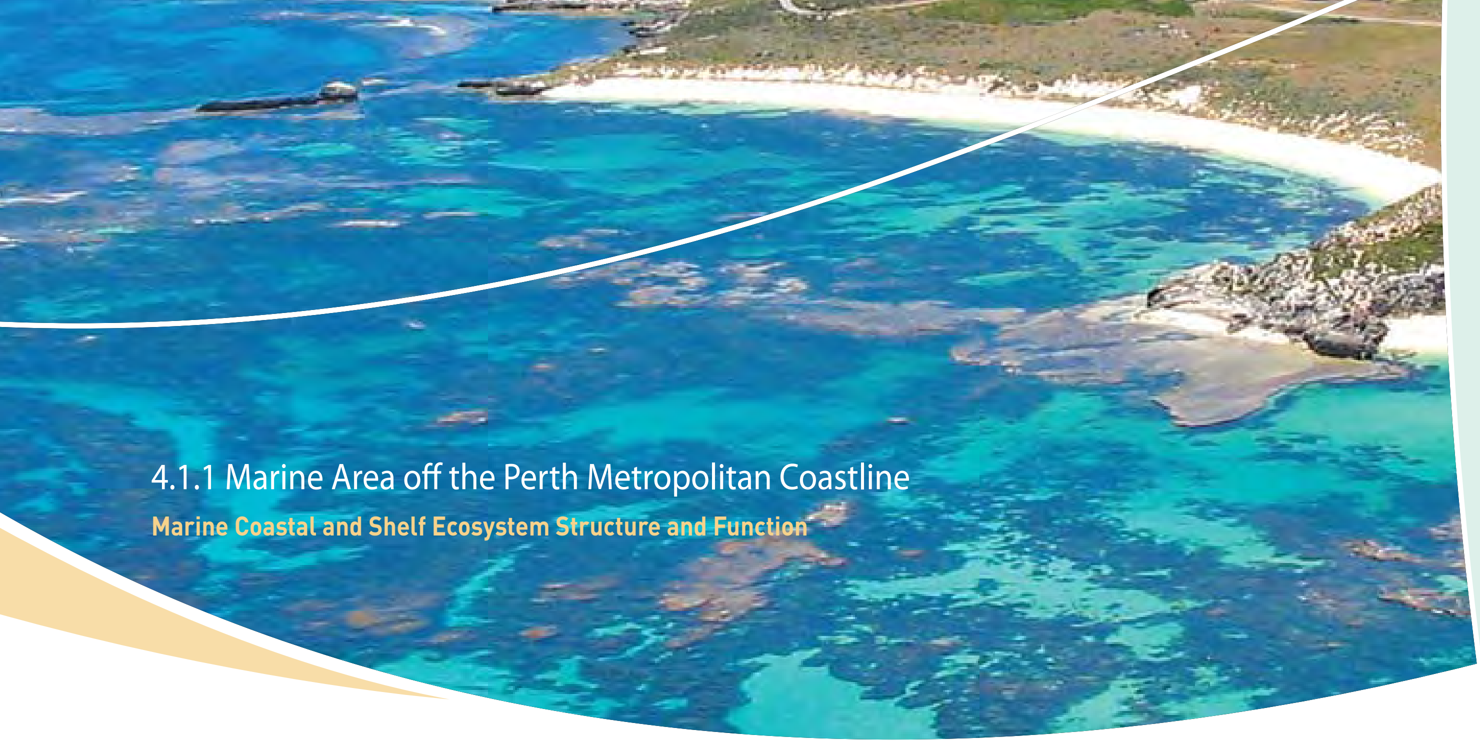
RESULTS AND HIGHLIGHTS

WAMSI has successfully undertaken a major program of strategic, multi-disciplinary, independent, collaborative research over the past five years. The approach has been to target large-scale and complex issues that are of concern to government, industry and the general public and that are better addressed by a multi-institutional, multi-disciplinary approach. The result has been a cooperative undertaking where data and information are shared, leading to a reduction in duplication and the generation of knowledge for improved decision making and greater efficiency. Community engagement and stakeholder communication has been a significant component of the effort. Research capacity has been enhanced through supporting students, young career researchers and through collaboration between research providers and agencies responsible for natural resource management. The cohort of post-graduate students employed in WAMSI projects will form the core of future researchers familiar with the WA marine estate and the knowledge needs of government and industry. There has been an important increase in research "social capital" that derives from the building of trust, cohesion, synergies and professional networks through collaboration across institutions addressing common problems. This increased transparency across a broad range of research providers has been a hallmark of WAMSI.

A summary of the research highlights and outcomes of WAMSI research over the period 2006-2011 is set out in the following discussion.

4.1 Ocean Systems Forecasting

WAMSI research into ocean systems sought to understand better the physical oceanic processes that influence the WA coast and shelf environment, the biogeochemical processes that influence the distribution and abundance of plants and animals that characterise WA marine ecosystems, and climate change effects on WA coastal and marine environments. Quantifying the physical environment is essential in order to understand biological (e.g. phytoplankton uptake of nutrients, dispersal of dhufish larvae) and chemical processes (e.g. nutrient recycling) as part of the knowledge needed for sustainable management of the marine estate. The spatial extent of much of the research was the whole of the WA coast with specific research targeted in particular regions such as the area off the Perth Metropolitan coastline, Ningaloo Marine Park, the West Coast Bioregion, the Northwest Shelf and more lately, the Browse Basin and the inshore Kimberley region.



4.1.1 Marine Area off the Perth Metropolitan Coastline

Marine Coastal and Shelf Ecosystem Structure and Function

Research in this region focused on improving knowledge and generating new tools to understand better the characteristics of the southwest Australian marine coastal and shelf ecosystem structure and function. Such research is intended to enhance the capacity to understand, predict and assess ecosystem response to human-induced and natural pressures.

Key outcomes for this research have been:

- The development of hydrodynamic models at nested scales for the South West Australian continental shelf (from 10km to 2-5km resolution) (Fig 4) down to lagoon scale (50-100m resolution) in Marmion Marine Park. These models have been calibrated with independently derived data such as from satellite and in-water instruments and help to understand the mechanisms that transport particles and nutrients through the water. The models have a wide range of applications in fisheries and marine park design and management, and can be applied to other parts of the WA coastline.
- The development of nutrient budgets that identify the source of nutrients and their pathways to benthic and primary production. Benthic primary productivity off the southwest (e.g. from kelp) is now estimated at three times higher than previous estimates. Between 80 and 90% of primary production on the continental shelf is dependent on recycling of nitrogen on the shelf rather than new supplies from the open ocean or terrestrial runoff. This macro-level information on the entire nutrient budget is important in understanding the carrying capacity and productivity of coastal fisheries such as that for the western rock lobster.
- New discoveries about the critically important mechanisms for supply of nutrients to fuel the annual autumn phytoplankton bloom that occurs off the entire mid and southwest shelf of WA have value-added to previous research (SFRME). This knowledge is important for fisheries and marine parks management, particularly if the patterns of nutrient supply and uptake are altered e.g. through climate change effects that are predicted to weaken the Leeuwin Current during autumn (see section 4.1.4).
- New understanding of the mechanisms for water circulation and exchange in Marmion Marine Park lagoon. Circulation is largely driven by wave forcing water over fringing reefs into the lagoon. These forces set up currents that can flush the lagoon in 15 hours or less. This rapid rate of exchange between coastal and shelf water has implications for the management of impacts of coastal developments such as sewage treatment plants and desalination plants. The models and research instrumentation approaches used can be relocated to other parts of the WA coastline.
- The development of a range of indictors of ecosystem health for inshore waters based on an assessment of the ecology and biogeochemistry of soft sediment habitats across a gradient of human impact. These indicators can be used to monitor and predict the impacts of coastal developments based on a given range of nutrient input and wave/swell exposure regimes.

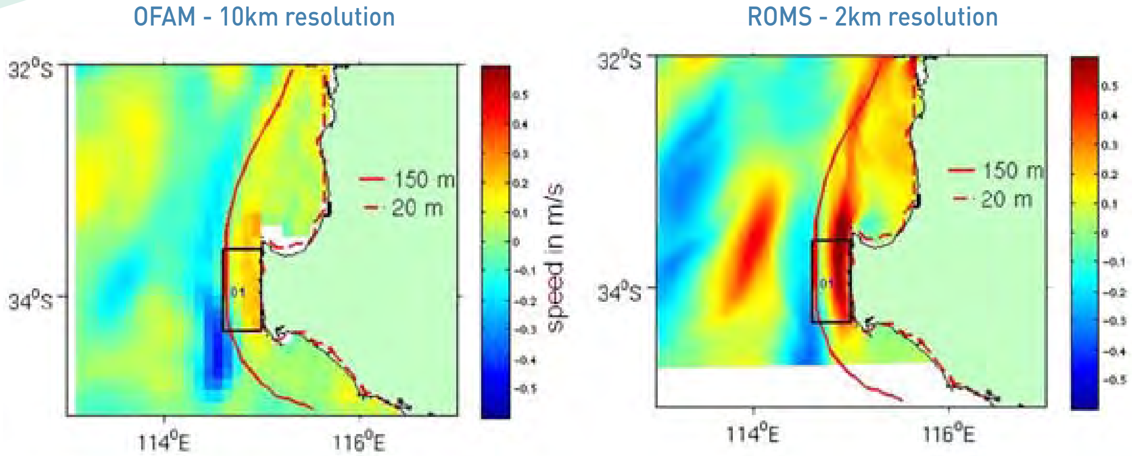


Fig 4 Example of nested models showing different current speeds. Finer spatial resolution generates higher and more accurate predicted current speeds.

Underwater Glider Technology for Marine Observations

WAMSI provided additional funding to complement the large (>$20 million) program of observations funded by Integrated Marine Observing System (IMOS) in Western Australia. Under this project, new multi-disciplinary marine data streams are to be provided through the deployment of a range of instrumentation such as HF Radar, ocean gliders, ocean moorings and acoustic observatories. These new data streams on ocean observations are essential for boundary current understanding and add substantially to understanding oceanic conditions offshore from the Pilbara and Kimberley coasts. The WAMSI funding facilitated the deployment and testing of ocean gliders in Western Australia. In addition WAMSI supported the business case to Government for the allocation by the State of $6 million in 2011 towards the development of new oceanic observing infrastructure in the north-west of WA.

The Slocum glider (Fig 5), which has a maximum depth capability of 200m, was deployed successfully and continuously for almost three years in the Perth region, off Two Rocks near Perth into and along the Perth Canyon off the edge of the continental shelf. One significant discovery has been the identification of new deep dense water flows cascading off the continental shelf into deeper water. This discovery of the Dense Shelf Water Cascade (Fig 6) has particular potential significance for cross-shore transport of water and particles such as nutrients and larvae.

Fig 5 Slocum Glider: Ocean gliders are autonomous vehicles designed to operate in deep water and contain a suite of sensors to measure conductivity (for salinity), temperature, dissolved oxygen, fluorescence, turbidity, dissolved organic matter and down-welling light with depth. By changing its buoyancy, the glider is able to descend and ascend.

4.1.2 Ocean Dynamics and Implications for Coastal Infrastructure and Offshore Structures

Sea levels and Wave Climate

WAMSI research has improved understanding of the combined effects of changes in the wind wave climate and the magnitude and frequency of storm surges, together with relative sea level rise due to climate variability and change on coastal systems and infrastructure.

An important outcome is that a detailed map of the mean sea level, astronomical tide, storm surge, and wave climatology of Western Australia has been created. Sea levels and wave climate over the period 1970-2009 have been hindcast for the whole of the Western Australian coastline. These will provide valuable time series for coastal assessment in regions where no tide gauge or wave buoys are located. A particular highlight of the research was the mapping of the inter-annual (18.6 and 4.4 year) tidal modulations, firstly for Western Australia and then on a global scale.

To achieve this outcome, there has been an integration of ocean observations and ocean numerical modelling capability. The ocean observations have required the development and implementation of new technologies, such as the use of ocean glider technology and dedicated fixed instrument systems. These observations have added to data streams from the federally funded IMOS program, as well as continuing ocean observations made by the oil and gas industry. This is relevant in the Kimberley region where future developments are in new previously unexplored waters on the edge of the Shelf and, particularly, in deeper waters over 1000 m. The new generation numerical models are hybrid models with the capacity to provide predictive capability from scales as large as 1000 km down to scales as small as 10 m. They integrate data-assimilating large-scale models, such as BLUElink, with process-oriented smaller scale models for specific regions of interest.

Another significant outcome of this research is a much improved understanding of the sea level and wave climatology of the region and coastal stability. This will assist in the management of existing coastal infrastructure and in improving risk assessments in the design of future facilities in West Australian coastal waters under the influence of climate change. It will also help determine the scale and resources required for flood risk management and planning throughout the 21st century, including upgraded coastal protection and more accurate definition of coastal setbacks. This work has already been used directly in revision of the Western Australian Coastal Planning Policy and for advice to the City of Wanneroo about the risks to buildings on the foreshore at Yanchep.

Although the focus of this research was on the entire WA coastline, the implications of the research have been applied to two specific locations - Peel/Harvey Inlet and Yanchep Lagoon (Box A and B).

Fig 6 Representation of underwater Dense Shelf Water Cascade off Two Rocks near Perth

Box A
Peel/Harvey Inlet

Peel/Harvey inlet was the focus of research across several Nodes and disciplines. This research addressed two broad areas of human/ environment interactions:

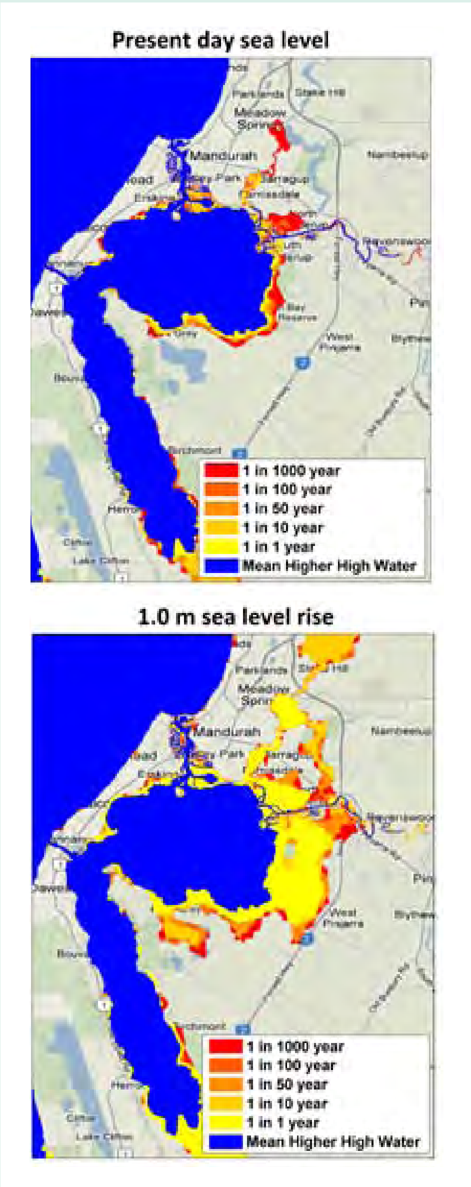


Fig 7 Comparison of present day sea level with possible flooding areas under different climate change induced sea level rise.

1. Future predictions of the effects of climate change on estuarine systems

Regional sea level and wave climatology modelling has been applied to the Peel/Harvey Inlet to provide a forecast of possible flooding areas under different climate change induced sea level rise over the 21st century. Fig 7 indicates the likely extent of flooding under a 1 metre sea level rise.

2. Current issues of ecosystem health and governance.

Qualitative and quantitative modelling of fisheries and governance issues was applied to the poor condition of the Peel/Harvey Inlet. The majority of risks in estuaries are due to anthropogenic effects other than fishing, including those associated with land clearing, agriculture, canal development, increased urbanisation and recreational use. Climate change, e.g. increasing temperature and decreasing rainfall and thus reduction in river flow and flushing of the estuaries, is also likely to have a compounding effect in the future. Risks are primarily to estuarine stocks of estuarine-dependent species, or marine species that utilise estuaries as a key nursery habitat. The health of the Peel/Harvey Estuary ecosystem is declining and further monitoring will not improve the health of the system. Multi-jurisdictional governance issues would need to be addressed in order to deal with the decline in estuarine health. Any improvement to estuarine ecosystem health will only come through taking a whole-of-catchment management approach to reduce impacts from land use on the estuary ecosystem.

Box B
Yanchep Lagoon

Field experiments over a range of temporal and spatial scales were conducted at Yanchep Lagoon, an example of a 'perched' beach, which are widespread throughout the southwestern Australian coastline. At least 25% of beaches in the Perth Metropolitan Area are perched due to the dominance of Quaternary limestone formations. The project used a wide variety of data sources (tide gauge data, wave buoy data, meteorological re-analysis, tropical cyclone tracks, and aerial photographs). A range of modelling tools was developed and extensive fieldwork (regular beach surveys, current and wave measurements, sediment flux measurements and surface current drifter tracking) undertaken at Yanchep over a cascade of temporal and spatial scales to determine how beach behaviour changes under different metocean forcings and how rock formations influence waves, currents and beach morphology. This information will be important for assessing possible beach erosion from increased storms predicted under various climate change regimes. The knowledge gained from this research has already been applied in an assessment report to the City of Wanneroo on the implications of sea level change for the development of coastal infrastructure (Figs 8a and 8b).

Figs 8a and 8b
Yanchep Lagoon
and Coastal
infrastructure

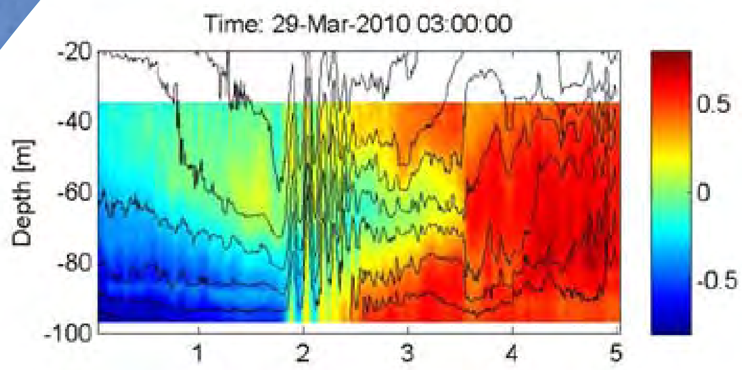


Fig 9 Graphic representation of Internal Wave - Browse Basin

Internal Waves and Offshore Infrastructure

WAMSI research, in collaboration with Woodside and other companies working in the North West Shelf, sought to characterise and quantify the physical forcings in this unique, remote and hostile environment where there are many oceanographic unknowns.

The region has input from the Indonesian Throughflow to the north and output in the Leeuwin Current to the south. There is complex shelf/slope topography, particularly in the northern regions and some of the largest tidal motions in the world occur there in turn inducing powerful internal waves and solitons. In many instances, these are the dominant physical processes in the marine environment and are thus often the dominant factor in engineering design criteria. The region also experiences intense tropical cyclones during the summer months. The scale and intensity of these physical processes are predicted to increase in response to climatic change.

Engineering priorities are to understand these diverse processes and their interactions to provide design criteria for current and future developments in the region. This is particularly relevant to future expansion of the industry into more remote and deeper waters, not only as it applies for near-surface conditions but also near the benthic boundary layer.

The processes by which internal waves (Fig.9) are generated, propagated and dissipated are now known, and a quantitative assessment of the intensity, spatial and temporal distribution of the currents and turbulence induced by these internal waves has been made. Further detail can be found at Box C.

The outcomes of WAMSI research in this field have been of immediate benefit to industry by providing a comprehensive understanding and predictive capability of the tidal motions and tidally driven internal wave climatology on the North West Shelf. Woodside Petroleum has already applied the technical information to the design of underwater pipelines and achieved substantial cost reductions for a number of oil and gas projects e.g. savings for the Sunrise Project are estimated at $20 million and for Pluto Project $5 million. Further savings are also likely to accrue for the North Rankin B Platform and associated infrastructure (Figs 10a and b).

Box C
Internal Waves and Offshore Engineering

This research was designed to provide both comprehensive understanding and predictive capability of the tidal motions and tidally driven internal wave climatology on the Australian North West Shelf. This covers the generation, propagation and dissipation of internal waves, and quantitative assessment of the intensity, spatial and temporal distribution of the currents and turbulence induced by these internal waves. The methods involved an integration of field measurements, the development and application of numerical ocean circulation models, and focused laboratory and theoretical studies.

Field measurement programs were undertaken at physically diverse locations to determine the characteristics of tides and internal waves in the energetic tidally dominated environment of NW Western Australia. The three field sites and programs were:

1) North Rankin A, area measurement/modelling program.

2) Browse Basin and Scott Reef measurement/modelling program.

3) Ningaloo Reef measurement program.

The main numerical modelling tool was ROMS (Regional Ocean Modelling System), an open source freely available hydrostatic numerical circulation model. ROMS needs large-scale climatological ocean information to provide initial and boundary conditions. This information was obtained from the BLUELink model. In this application, ROMS is driven by the tidal forcing obtained from the TPXOv7.1 global tidal model and is applied to the North West Shelf with varying domain scales of up to approximately 2000 km by 800 km, and with horizontal spatial resolution down to scales of 1 km and with typically 50 sigma layers in the vertical. ROMS is typically run on timescales of a month. The model can then be used to set up a second model SUNTANS and this has been used mainly in the Browse Basin region. SUNTANS (Stanford UNsTructured Adaptive Navier Stokes Solver) is a fully non-hydrostatic model and is run in unstructured domains of approximately 100 km by 100 km with horizontal spatial resolution down to scales of 75 m horizontally and up to 150 z-layers in the vertical. It is computationally intensive requiring large parallel machine computations and is able to resolve the high-energy non-hydrostatic flows and internal waves, which are seen at some locations on the North West Shelf.

Data from the field sites was used to evaluate the model results and overall quality of the predictions, to test model descriptions of specific processes such as mixing intensity and energy fluxes and current speeds, and generally optimise model performance. Beyond this step, the model could then be used with confidence to predict ocean behaviour at sites were no measurements were made or available. In essence, the models can then be used to forecast ocean behaviour, and this method was used in both the Southern North West Shelf region around North Rankin A and the Browse Basin region.

Fig 10a

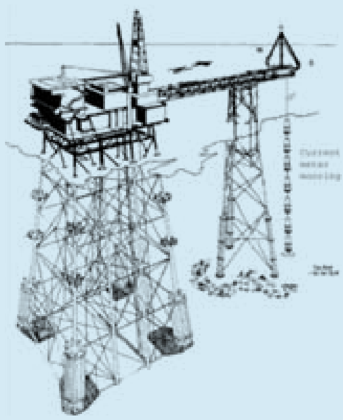


Fig 10b

Figs 10a and 10b Drilling Platforms

4.1.3 Climate Change Effects on Coastal and Marine Environments

Much of the research in this area sought to test and apply global, regional or national forecasting systems to the WA marine environment, for example the Predictive Ocean Atmosphere Model for Australia (POAMA), a dynamic computer model of the Australian climate system at the Bureau of Meteorology that provides forecasts of the El Niño Southern Oscillation (ENSO) phenomenon. WAMSI research also sought to improve understanding of the predictable large-scale climate variations of the Indian and Pacific Oceans arising from ENSO, the Indian Ocean Dipole (IOD), the Madden Julian Oscillation and their interaction with the marine and terrestrial environments of WA.

A global ocean circulation model, the BLUElink model, has been used to downscale the future climate change scenarios for ocean boundary currents surrounding Australia, which has underpinned the climate impact downscaling research on the Ningaloo Reef as well as providing the basis for Department of Fisheries WA climate adaptation research. Using field observations and numerical modelling, the project has improved knowledge of Leeuwin Current warm and cold core eddies (Fig 11) and their role in nutrient and fish larvae transport off the west coast of WA (see also Section 4.1.4) The ability to provide seasonal predictions of the variations of the Leeuwin Current has great potential for improved management of the WA marine environment.

The outcomes of this research have been both important for improving understanding of WA ocean systems and climate variability but also in helping improve national and regional models for climate change predictions.

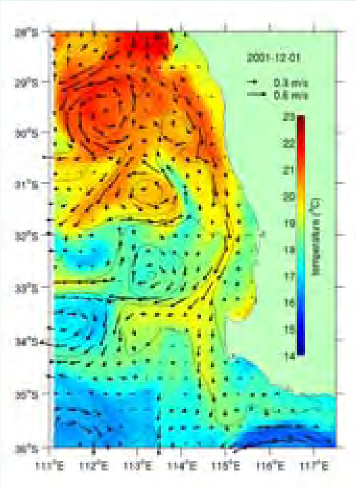


Fig 11 Model representation of Leeuwin Current eddy formation off the WA coast

WAMSI research has demonstrated the ability of the POAMA system to predict the large-scale drivers of variability of the marine environment of WA, with a focus on the strength of the Leeuwin Current. This research has also contributed to the future development of the national POAMA seasonal forecast system, especially the need to eliminate systematic model bias and the need to properly simulate El Niño and its remote impacts.

WAMSI research has enhanced understanding of the mechanism for the year-to-year temperature variability off the lower west coast of WA. It has also detected the multi-decadal strengthening trend of the Indo-Pacific circulation and the Leeuwin Current since early 1990s, which is likely to be part of natural climate variability.

WAMSI research has assessed climate change impacts on the marine environment off Western Australia, particularly those that influence the Leeuwin Current. Interannual variations of the Leeuwin Current are strongly influenced by the tropical Pacific climate, for example volume/heat transports and eddies are stronger during La Niña years.

This research has contributed to the capability to downscale and project seasonal forecasts of the Leeuwin Current variations into the marine environment of the continental shelf using the technology of nested climate models from oceanic to local scales. This knowledge is critical to better understanding of the role of nutrients for fisheries productivity and in the planning for coastal infrastructure, in the context of climate change (see also Section 4.1.4).

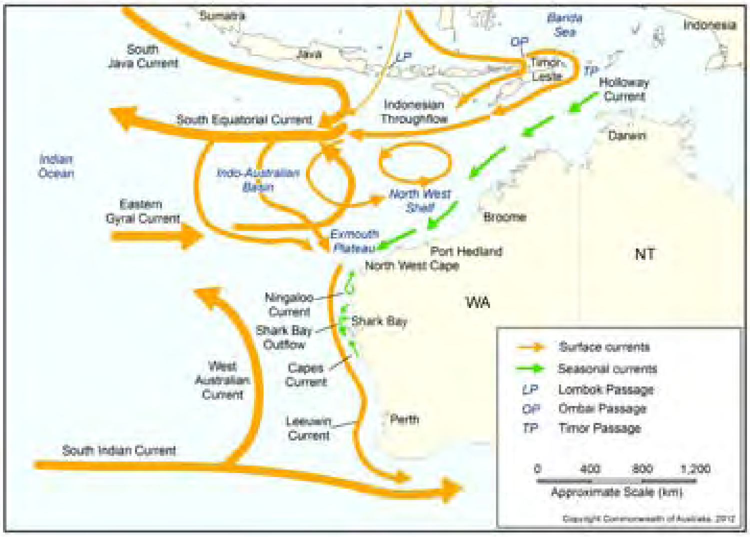
There is now a significantly improved understanding of:

- the key drivers of variations of the WA marine environment and the Indian Ocean climate, El Niño and the Indian Ocean Dipole phenomena in the Indian Ocean;
- the limits of predictability of large-scale climate variations in the Indo-Pacific region that drive variability of the Western Australian marine environment; and
- the impact of intraseasonal variability for prediction and evolution of large-scale circulation in Indian Ocean.

Products from this research include web-based enhanced and experimental seasonal forecasting models tailored to the WA marine environment.

4.1.4 Leeuwin Current and its Importance for WA Marine Estate

The Leeuwin Current is a warm, poleward flowing ocean boundary current off the west and south coasts of Australia, driven by large-scale north-south pressure gradient. The strength of the Leeuwin Current is influenced by ENSO-related thermocline anomalies, and is the result of strong current flow from the equatorial western Pacific into the southeast Indian Ocean through the Indonesian Archipelago. The Leeuwin Current is stronger in winter than in summer, and its interannual variability has profound impacts on marine ecosystems off the west and south coasts of Australia (Figs 12a and b). For example, a strong Leeuwin Current and associated warmer water temperatures is a major influence on increased recruitment to the WA western rock lobster (*Panulirus cygnus*) fishery.



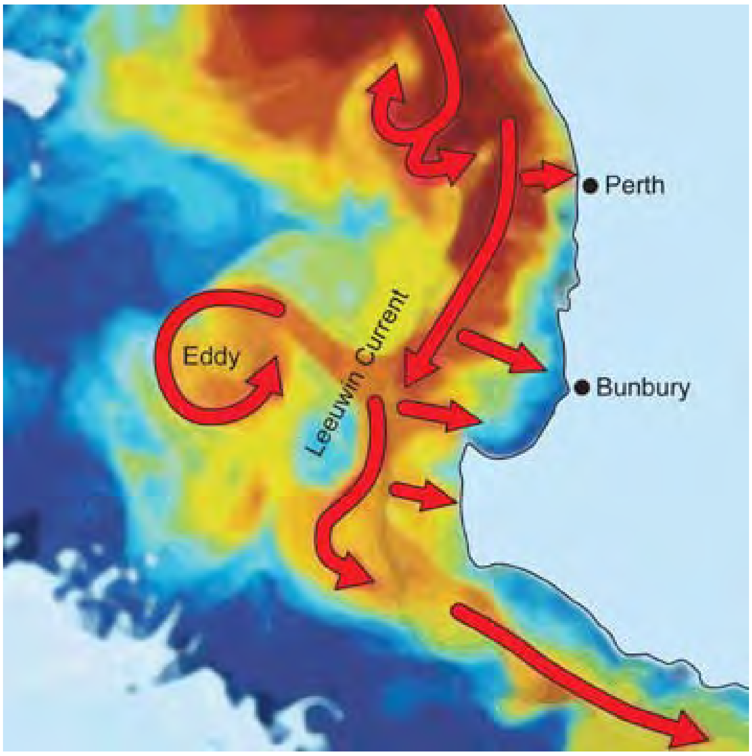
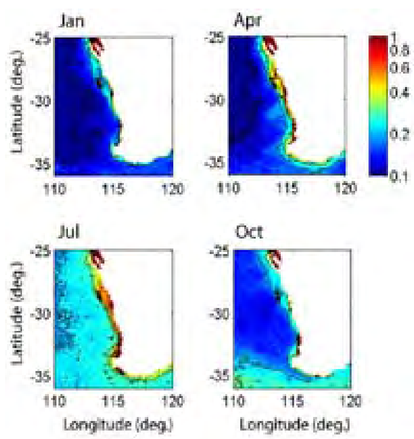


Fig 12a Ocean Circulation Pattern off Western Australia
Fig 12b Leeuwin Current and Eddy

Phytoplankton Bloom

An autumn phytoplankton bloom occurs annually off the entire mid and southwest coast of WA. This bloom is a critical source of nutrients for marine organisms and particularly for fisheries recruitment and production. Most of the total nutrient budget (c. 80%) that supports continental shelf production is recycled annually on the shelf. However the source of additional nutrients and the mechanisms by which they were entrained were largely unknown until recently. Through WAMSI research, there is now an improved understanding of the importance of offshore/onshore exchange of water, longshore transport, and upper ocean mixing processes on nutrient supply to the shelf. The Leeuwin Current is the critical transport mechanism that provides additional nutrients to shelf-based recycled nutrients that fuel this annual autumn phytoplankton bloom. Deep layer nutrients from the northwest of WA are advected in late summer - autumn by the Leeuwin Current into the shallower euphotic zone off the southwest (Fig 13) making it available to the marine plants to bloom. Wave action that stimulates nutrient resupply from sediments on the shelf is also important during winter (see Section 4.1.1). The recycled shelf-based nutrients tend to fuel microbial growth, which supports small phytoplankton, whereas the offshore nutrients contribute to large phytoplankton growth which is likely more suitable for larvae such as late stage western rock lobster phyllosoma. This knowledge is important for fisheries and marine parks management, particularly if the patterns of nutrient supply and uptake are altered e.g. through climate change effects that are predicted to weaken the Leeuwin Current during autumn.



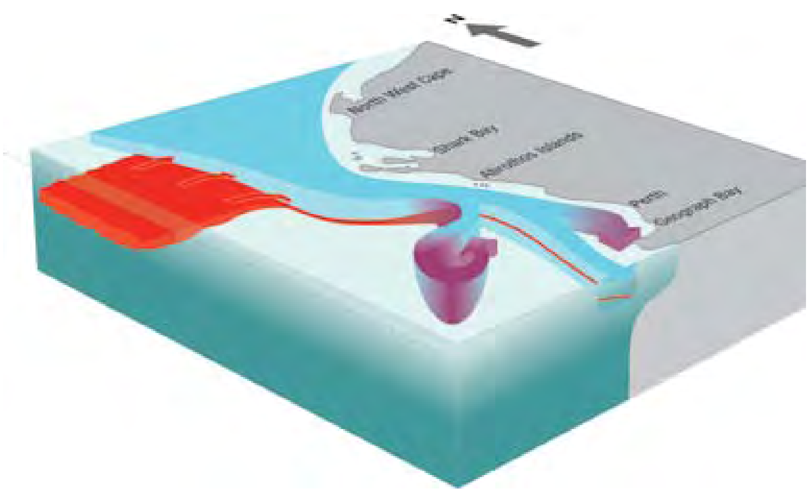
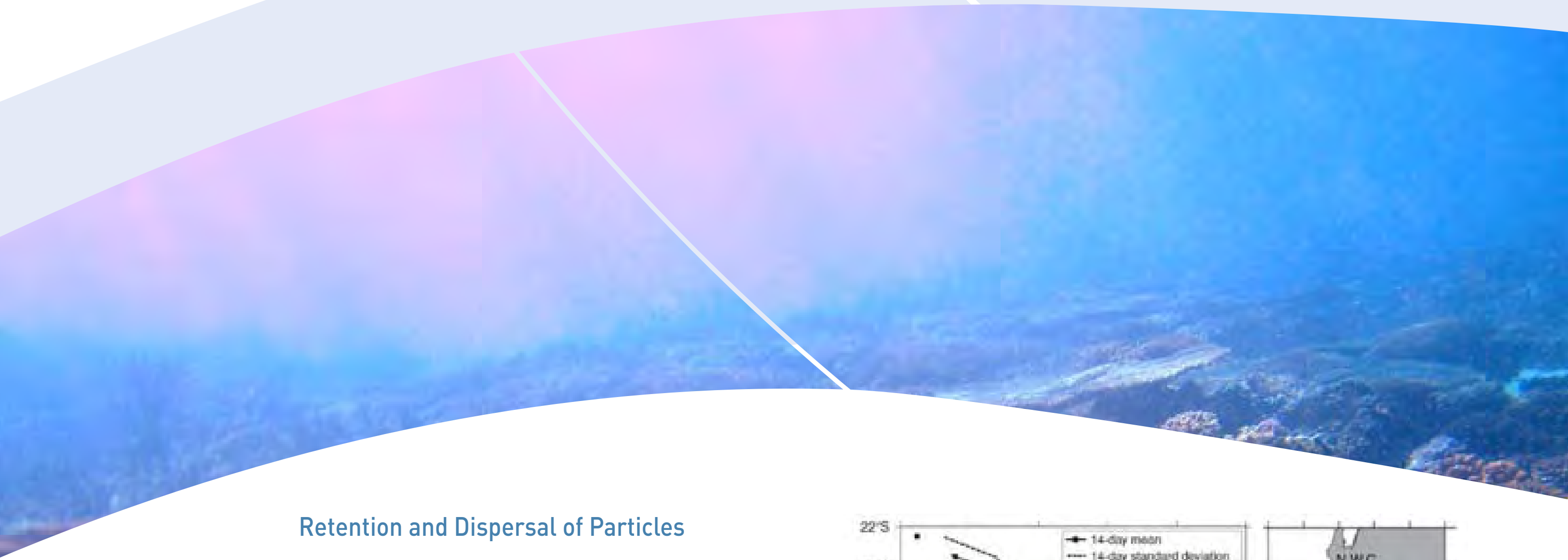


Fig 13 Model showing additional nutrient entrainment by Leeuwin Current from the northwest into the south west



Retention and Dispersal of Particles

WAMSI research has confirmed and strengthened the previous understanding of the role of the Leeuwin current in the transport of particles (eggs, larvae and nutrients) southwards along the WA coast and its relationship with cross-shelf flows, both shoreward and seaward. Between Northwest Cape and Cape Leeuwin the transport and interactions with shelf waters is not uniform and varies according to the coastal morphology. Different parts of the coastal shelf waters "retain" and "disperse" water and any particles at different rates. In some sections of the coastal shelf, particles are rapidly flushed while in others they are retained longer, allowing for dispersal and settlement. Such knowledge of how eggs and larvae of marine animals and their food will be dispersed or retained along the WA coast is important for marine parks and fisheries planning and management. For example, the grounds for the highly productive coastal scallop fisheries in the south west of WA coincide with areas of high larval "retention" while those areas that lack scallop fisheries are in high larval "dispersal" areas (Fig 14).

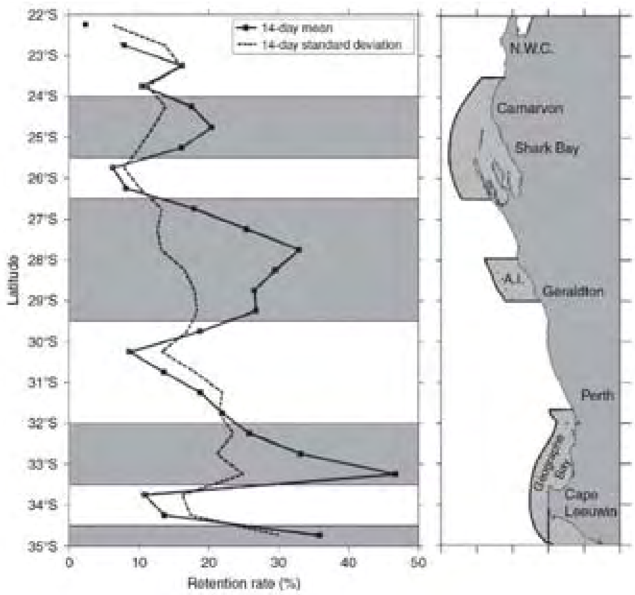
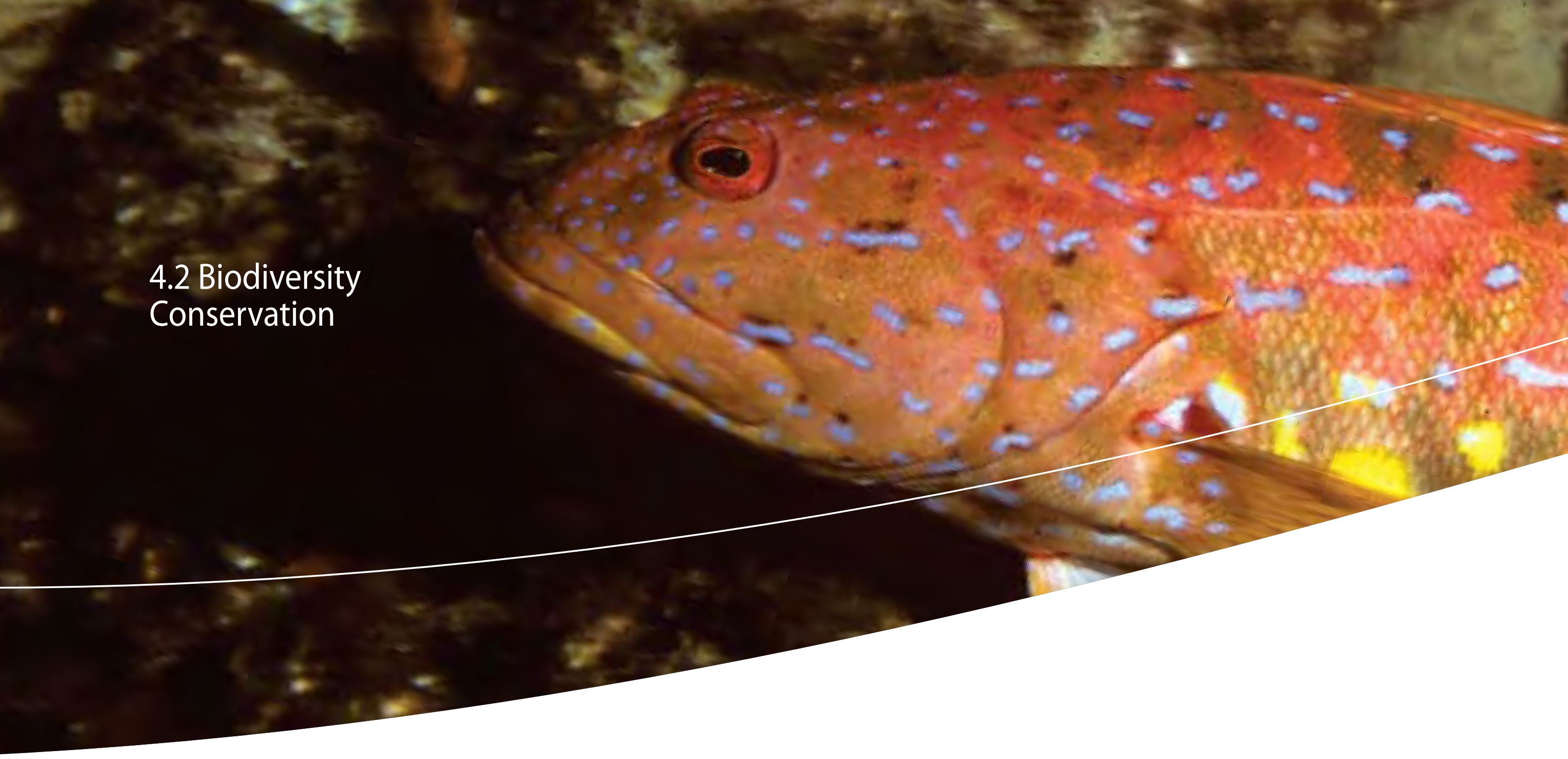


Fig 14 Larval retention areas and scallop fishing grounds

"Understanding larval dispersal provides important information about population connectivity, population persistence or sustainability, effectiveness and design of management strategies such as marine protected areas. Cowen et al 2000."



4.2 Biodiversity Conservation

4.2.1 Ningaloo Marine Park

In 2005, the WA Government, in recognition of the importance of Ningaloo Reef, allocated $5 million for research to support management of the Ningaloo Marine Park. This program was incorporated in the broader WAMSI research program in 2006. The initiative attracted significant co-investment in the form of the Ningaloo Collaboration Cluster, a program of complementary research funded by CSIRO Wealth from Oceans Flagship and led by Murdoch University. Core funding of $2.5 million for the Cluster program was provided through the CSIRO Flagships Collaboration Fund and supplemented with additional funds and in-kind support from CSIRO, AIMS, Department of Environment and Conservation (DEC), University of Western Australia (UWA), Curtin University of Technology (CUT), Edith Cowan University (ECU), BHP-Billiton and the Sustainable Tourism Cooperative Research Centre (CRC).

This collaboration leveraged the original $5 million of State funding into $36 million in cash and in-kind support over the period 2006-2011. The combined research programs involved over a 100 scientists across multiple disciplines from eight research organisations in 47 major research projects.

The research program was based on information needs identified in the Management Plan for the Ningaloo Marine Park and the Muiron Islands Marine Management Area 2005-2015 (Fig 15). The following general themes derived from the management plan provided the framework for the combined research program:

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

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

Outcomes

A much more comprehensive baseline of knowledge and data for Ningaloo Marine Park has now been established, against which to measure future change, whether from direct or indirect human actions, including climate change. The effects of this investment will be felt for years to come, through the publication of results, the application of knowledge to

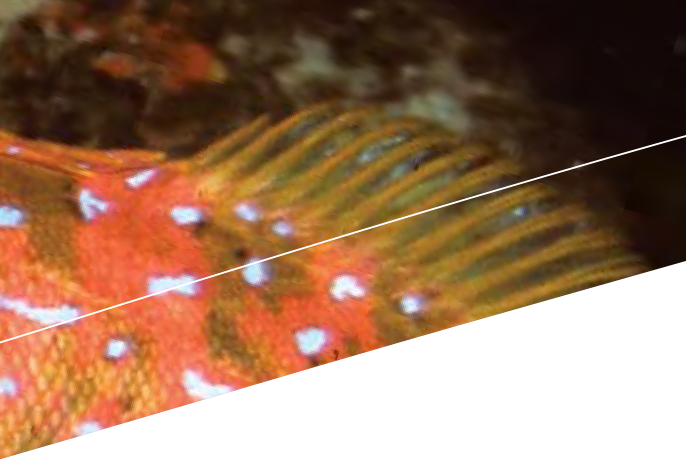


Fig 15 Map of Ningaloo Marine Park

management decision making and through better community understanding of the ecological processes and effects of human use on the resources of Ningaloo Marine Park. Such understanding should assist government, industry and community to address any future challenges to values, uses and conservation of this iconic place and its adjacent coastal area.

The research undertaken has contributed substantially to the declaration in June 2011 of the Ningaloo Coast as a World Heritage Area (Fig 16), in recognition of its status as a biodiversity 'hotspot' as well as an iconic destination for local, State, Australian and international tourists.

There is now a far better understanding of the physical and biological features that comprise Ningaloo Marine Park. This includes background and baseline information on the physical structure of the reef along with its history and growth and the type and distribution of benthic habitats and associated faunal communities inshore and offshore and latitudinally. The diversity, abundance and distribution of many species that inhabit Ningaloo Marine Park including intertidal invertebrates, target fish species and sharks are much better understood. Knowledge of the ecological and physical processes that feed and support the reef system has improved markedly, including behaviour of oceanic currents and local hydrodynamic regimes that bring food to the reef in the form of phytoplankton.

The whole marine park and adjacent coastal areas has now been surveyed intensively to produce maps of the distribution and characteristics of seabed benthos and sediments using a variety of methods (see Box D) Mapping Ningaloo Marine Park). There is now a detailed data set that allows for modelling the trends and changes in key indicators over future years.

Sanctuary Zones established in 2005 and in earlier zoning plans have been demonstrated as broadly representative of the diversity and range of habitats and species that characterise Ningaloo Marine Park. In particular surveys of deepwater Sanctuary Zones have revealed extensive sponge gardens (40% of the world's sponge species are found off the WA coast) with many species hitherto unknown to science. These discoveries may provide the basis for significant biodiscovery and biotechnology industries in the future (see Section 4.3.4).

Improved understanding of the thermal structure and local hydrodynamic processes within the lagoon and adjacent to the reef structure will assist in understanding the potential effects of climate change on the Park, such as coral bleaching induced by elevated sea surface temperatures (SST). The reef system is normally buffered from higher water temperatures by cooler water flushing the lagoon at regular intervals from the northward flowing wind driven Ningaloo Current. However in February 2011 an unprecedented bleaching event occurred in an area extending from Ningaloo to the Abrolhos Islands and over 200km offshore with average surface temperatures more than 3°C above average for this time of year. Weakening of the Leeuwin Current (further predicted with climate change) and/or seasonal changes in the wind-driven Ningaloo Current could reduce the current level of buffering of the lagoon from higher water temperatures and increase the likelihood and frequency of coral bleaching and death. (see Box E 'Marine Heatwave')

Bioregionalisation

The physical and biological research at NMP shows unique distributions of the biodiversity with profound implications for the management of the region. As expected, biodiversity and species assemblages vary with water depth and habitat (i.e. the lagoon system contains different species assemblages from the reef slope, reef crest and deeper waters seawards of the reef). However, latitudinal differences in assemblages of plants and animals are suggesting strong bioregional separation within NMP. Ningaloo Marine Park is exposed to both tropical and temperate oceanographic influences which, combined with variations in topography and geomorphology of the region, have produced distinct bioregionalisation of NMP. There are very different species assemblages in the northern and southern ends of NMP. An example is the distribution of rock lobster species. One temperate species is commonly found in the southern end of the marine park whereas in the north four species are present. Similar patterns were reported for fish species. Rich assemblages of deepwater benthic species vary significantly throughout the Park with each location significant in its own right and deserving of specific conservation effort.

Point Cloates in the centre of the Park stands out as a broad transition area from tropical to temperate influence but also contains its own unique biodiversity and assemblages due to the complex habitats created by a series of benthic pinnacles and ridges.

This variation in species distribution throughout the park has very important management implications and in particular, the management of biodiversity values. Zoning plans and other management arrangements will need to provide adequate protection for the different biodiversity assemblages throughout the park. Temperate and tropical species may be at the boundary of their range and the habitat in NMP may be sub-optimal for a number of species. Some species of commercial or recreational interest may require special protection to ensure that they remain sustainable. The unique gradient of species and assemblages at NMP provides an ideal location for monitoring potential effects of climate change on key species and their environment.

Fig 16 Ningaloo Coast World Heritage Area boundary, including Ningaloo Marine Park.

Box D
Mapping Ningaloo Marine Park

Mapping the distribution of habitats and substrate type has been a major achievement. An essential first step in understanding the biodiversity of an area is to map the distribution and abundance of the biodiversity and the seabed on which it rests. Data on bathymetry, sediments, seabed composition, biodiversity, water movements and water chemistry can then be used to model the processes that drive the distribution and abundance of biodiversity. This information can in turn allow the interpretation of changes to the biodiversity from human or natural causes. A variety of methods were used over the 5 years to generate high quality maps of habitats and seabed characteristics. For the shallow clear inshore environments, optical remote sensing with airborne hyperspectral equipment was used to detect and map the distribution of seabed habitats such as sand, limestone pavement, rubble, macroalgae, hard and soft coral growth forms. Additional data was then collected with underwater surveys of selected areas of the NMP using techniques such as underwater video and still drop camera systems to identify specific substrate and habitats, and dominant species at finer scales than that achieved from airborne equipment (Figs 17 a and b).

For deeper water habitats (i.e. beyond the shelf break in depths of >20 metres and up to 110 metres depth), a variety of remote sampling techniques were used. Towed underwater video cameras and drop cameras were used to develop broad scale characterisation of biodiversity and habitat types; to improve understanding of bathymetry, single beam and multi-beam depth sounders were used; for fish surveys, baited remote underwater video cameras (BRUVs) were used. One of the unexpected results was the discovery of deepwater sponge beds, comprising many new species and potential sources of organisms for future biodiscovery (see Section 4.3.4)

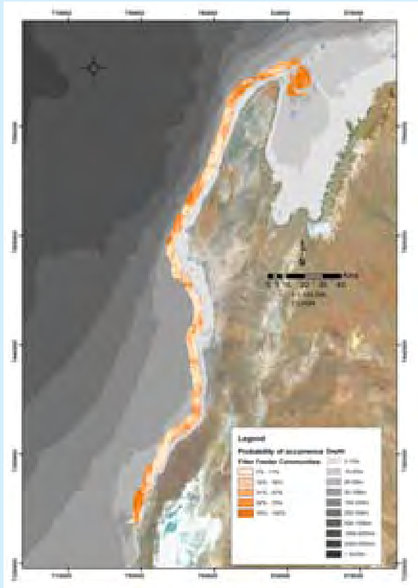


Fig 17a Example of predictive habitat map produced from remote sensing and towed video data. Spatial models and their outputs, such as maps predicting the probability of occurrence and likely location of specific habitats, provide new insight into the distribution of biodiversity in the deeper waters of Ningaloo Marine Park. B. Radford AIMS

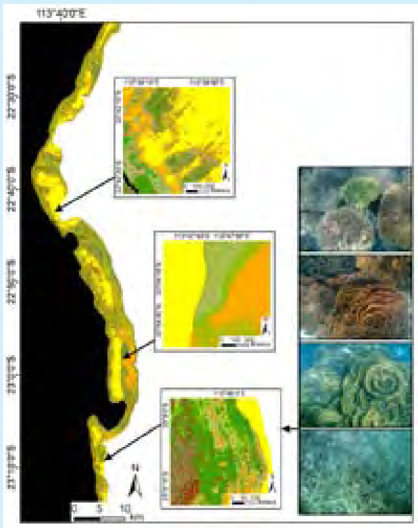


Fig 17b Example of habitat maps derived from remote sensing in the area north of Coral Bay. Red colours show hard coral cover, shades of green, macroalgae, orange to brown, limestone pavement and yellow indicates sand. Insets illustrate detail over smaller areas.

Modelling

The multi-disciplinary nature of the combined research programs allows for evaluation of regional scale management strategies. Modelling exercises undertaken as part of the combined Ningaloo research programs have produced tools that will be valuable aids to management decisions and community consultation. Simulation techniques known as Management Strategy Evaluation (MSE) (Fig 18) were used to explore the effectiveness of current management arrangements, and the consequences of alternative management actions and alternative future scenarios. One of the simulation models, the Effects of Line Fishing Simulator (ELFSim), was applied to the management of a major recreational fishing target species spangled emperor *(Lethrinus nebulosus)*(Fig 19). Stakeholder workshops applied the model to possible future management actions, given a range of alternative ecological and socio-economic objectives. This process evaluated the effectiveness of current management arrangements, clarified trade-offs inherent in pursuing different ecological and social objectives, and examined alternative future scenarios for management of Ningaloo Marine Park and its recreational uses, in the context of climate change.

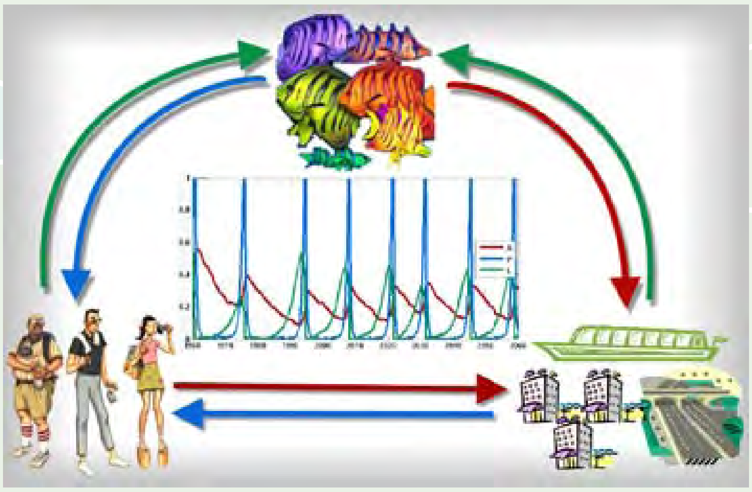


Fig 18 Model of the Management Strategy Evaluation Process. This important model developed by the CSIRO Wealth from Oceans Flagship Program was applied to the Ningaloo Cluster Research Program for specific use at Ningaloo Marine Park.

The Tourism Destination Model for Ningaloo Coast developed as part of the Ningaloo Cluster Program will be a valuable aid in tourism planning in coming years. For example the Exmouth Shire intends to use this model in the development of a Shire tourism strategy in 2012.

The research has also examined the level of human impact on the resources and values of the Ningaloo Marine Park and effectiveness of current management strategies. In general terms Ningaloo Marine Park is a relatively pristine coral reef environment; however human pressures from recreational fishing and tourism have had some significant impacts, with reductions in target species of finfish, lobsters and some molluscs.

Fig 19 Spangled Emperor

Sanctuary Zones

The size and location of sanctuary zones within NMP has been a particular focus for research over the past five years. Sanctuary Zones first established in 1991 and expanded in 2004 have shown positive outcomes for biodiversity protection. Substantial evidence has been produced that Sanctuary Zones are protecting populations of important target fish species such as spangled emperor *(Lethrinus nebulosus)*. This species is an important recreational target fish species for local fishers and tourists and is potentially vulnerable to shore-based fishing. Although stocks have improved inside sanctuary zones, research has also shown that stocks of this species over the whole Park have declined since 1991. Similarly stocks of other recreationally important finfish species show variations in abundance that correlate with fishing pressures. Rock lobster numbers still remain low and patchy in distribution despite the end of commercial exploitation in the 1980s. Historical records suggest that shell species were heavily collected in the northern part of the park in the 1960s, and have yet to recover.

In summary, the principle outcomes from this component of WAMSI research are:

1. Significantly enhanced capacity to manage human use and values and to evaluate future risks, including those likely to arise from climate change;
2. A suite of sophisticated management tools that have improved the predictive capacity and enable scenario planning for marine park management, tourism planning and fisheries management;
3. Improved capacity to deliver efficient and effective conservation and management programs in Ningaloo Marine Park and other marine parks for government, through the development of indicators, monitoring protocols and evaluation models;
4. Value-added research effort in Ningaloo Marine Park through collaboration with other initiatives and programs e.g. CSIRO Collaboration Cluster, IMOS, C-Reefs, AATAMS, Geoscience Australia;
5. Improved community awareness and support through training and involvement in research, new tools and communication about research purpose and results e.g. workshops in Perth and Ningaloo region, MSE discussions with community, researchers, managers and industry;
6. The investment by BHP-Petroleum in the development of the Ningaloo Atlas through AIMS. The Atlas is an interactive web-based tool that will utilise the data sets from the Ningaloo Research Program and make them publicly available to anyone who wishes to use them;
7. Development of improved links and collaboration between research institutions, government agencies, NGOs, industry and other end users;
8. Enhanced knowledge base and ability to apply learning from Ningaloo Marine Park to other marine conservation and tourism management scenarios throughout the State; and
9. Enhanced research capacity that will deliver returns in future years through students supported under the program.

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

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

The recognition of these outcomes, particularly those related to knowledge transfer, will be critical to the on-going use of this new knowledge in the conservation and management of NMP.

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

4.2.2 South West Region

WAMSI researchers working offshore of Marmion Marine Park have made the first discovery anywhere in the world of deep water sponges which possess high levels of photosynthetic symbiotic cyanobacteria. Researchers also discovered that sponges from Marmion excrete significant amounts of nitrogen in the form of nitrate. These important findings suggest that sponges in temperate waters off WA may play a critical role in producing and recycling carbon and nitrogen. Sponges (like corals in the tropics) are long lived animals and, apart from the important role in stabilising deepwater sediments, they can store and recycle large amounts of nutrients and may be critical in helping maintain the high deepwater primary productivity for coastal reefs and for key benthic fisheries such as western rock lobster.

Important discoveries about the role of kelp patches, as one of the key ecological feature of WA's productive coastal reefs, have been made. Kelp patches are the most productive parts and contain the highest store of carbon in living organisms in southwest WA marine ecosystems. By calculating nutrient budgets that identify the source of nutrients and their pathways to benthic and primary production, it is now known that benthic primary productivity from kelp off the southwest coast is three times higher than previous estimates. Between 80 and 90% of primary production on the continental shelf is dependent on recycling of nitrogen on the shelf rather than on new supplies from the open ocean or from terrestrial runoff. This information is important in understanding the carrying capacity and productivity of coastal fisheries such as that for the western rock lobster.

In addition, the processes by which kelp canopy patches and kelp-free patches are maintained and replaced after storms are much better understood. Understanding the longevity of transient features of the marine habitat like kelp beds is critical for the design and management of marine parks. WAMSI researchers found that recovery of former kelp patches that have been made bare e.g. through storms, can take 6-10 years before the kelp canopy returns. The effects of climate change in affecting the strength and frequency of storms that can tear up and disturb kelp beds will impact the resilience of this important structuring ecosystem and the organisms that depend on it.

Marmion Marine Park (Fig 20) was also one of the sites to test the effectiveness of small marine sanctuaries. Research has shown that effectiveness is dependent on both the time the sanctuaries have been in place and their size. The research showed that small sanctuaries are ineffective at protecting biodiversity and that even large sanctuaries must be in place for many years before they have a positive impact on biodiversity conservation.

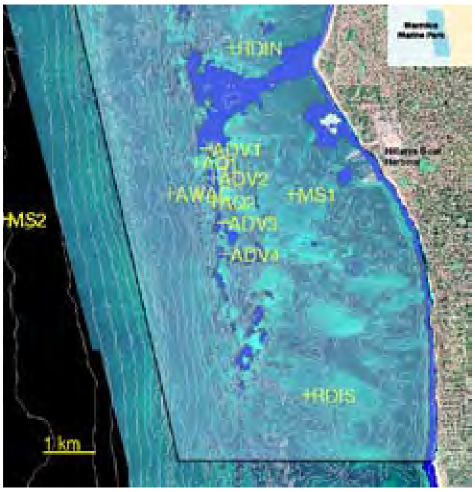


Fig 20 Southern part of Marmion Marine Park off Perth

Indicators of Ecosystem Health

WAMSI research has identified a range of indictors of ecosystem health based on an assessment of the ecology and biogeochemistry of soft sediment habitats across a gradient of human impact. The indicators identify the characteristics of nearshore and offshore coastal conditions from baseline condition through various altered states to degraded condition and provide a suite of parameters (e.g. nutrients, chlorophyll, light attenuation, micro-algae and sediment organic matter) that can be used to assess condition and identify sources of impacts. These indicators can be used to monitor and predict the impacts of coastal developments based on a given range of nutrient input and wave/swell exposure regimes.

Outcomes

The main outcomes from this research has been significantly improved understanding of the effectiveness of marine sanctuaries in conserving biodiversity, the role of deepwater sponges in carbon and nutrient production and recycling, the relative importance of recycling of carbon on the shelf (and the role of kelp in this process) and the importance of kelp as a structuring species and its possible vulnerability to increased storms. These outcomes will be important enhancements of fisheries and marine conservation management capabilities in the coming decades.

4.2.3 Kimberley Coast – A New Frontier

Although the primary focus for WAMSI in the period 2006-2011 was the marine region south of Exmouth Gulf, a strategic decision was taken to explore the emerging marine science needs for the Kimberley Browse region (Fig 21). The decision by the WA Government to establish a gas-processing hub on the coast north of Broome for gas from the Browse Basin, added a further imperative to understanding the current state of knowledge of the marine environment from the coast to deepwater. A coupled science-business case *A Turning of the Tide – science for decision making in the Kimberley-Browse Region* was commissioned by WAMSI in 2007 (Fig 22). The WA Government has recognised the marine research program outlined in the report as essential support for the State's Kimberley Science and Conservation Strategy released in 2011 and has allocated $12 million towards a new research Node in WAMSI 2 for this purpose. The proposed science will support the information base used in planning for four new marine parks in the region, as well as broader multiple-use and regional contextual issues.

Prior to the decision of the State Government on the preferred site for the location of the Kimberley gas-processing hub, WAMSI was commissioned to undertake urgent habitat surveys of candidate sites along the coast north and south of Broome. This project demonstrated the strength of WAMSI with its capacity to efficiently coordinate research effort and deliver results within tight timetables. CSIRO, AIMS and the Department of Environment and Conservation, with logistic support and planning advice from the Department of Fisheries WA, combined to provide a swift and comprehensive response to the request of government to characterise the marine habitats in the vicinity of James Price Point and other possible hub sites in the period May-July 2009. The WAMSI protocols already established for coordination and management of research, as well as for the publication of results, were a key factor in the speed and efficiency of this response. This capability was also demonstrated in the response following the 'marine heatwave' event in February-March 2011 (see Box E)

Fig 21 Aerial image of Kimberley Coast

Fig 22 "A Turning of the Tide – science for decision making in the Kimberley-Browse Region" – www.wamsi.org.au

4.3.1 Ecosystem Based Fisheries Management

WAMSI investment has enabled a fundamental change in the way fisheries are managed in WA. WAMSI funding has been the catalyst for development of a policy and operational framework for EBFM. Historically, fisheries management has been primarily based on single fisheries stock assessment, with little reference to other parts of the ecosystem. The adoption of Ecologically Sustainable Development (ESD) in the 1980's led to the development of ecosystem-based approaches to management of individual fisheries, now widely practised in Australia and overseas. These approaches used a risk-based framework to examine the impacts on target species, by-catch species and habitats and indirect effects on the wider ecosystem. However fishery level assessments did not address the combined effects of all fisheries within a region; nor did they consider cross-fishery allocation issues or the social and economic aspects of fisheries. The EBFM approach, now adopted by the Department of Fisheries WA, uses a risk based assessment process that evaluates the cumulative effects of all fisheries-related activities (commercial and recreational) in a region (including fish stocks, habitats and ecosystems) and integrates ecological, social, economic and governance aspects into fisheries management. Although EBFM is being considered to varying degrees in other fisheries management agencies in Australia and overseas, WA is leading the world in the full implementation of this initiative into management practice.

The outcome is a system that requires management of all ecological impacts and socio-economic outcomes related to any charter, recreational, commercial, indigenous fishery, or 'no-take' sector at a bioregional level (see Fig 23).

The initial application of the framework has been in the West Coast Bioregion which is the mainly temperate marine zone strongly influenced by the Leeuwin Current. The major fishery in this region is the western rock lobster fishery - Australia's most valuable single-species fishery with an average catch of 11,000 tonnes and value of $300 million p.a. Other valuable fisheries in this region include those that target scalefish, abalone, scallops and smaller pelagic fishes. All fisheries management plans will be reviewed over the next five years using the EBFM approach.

Outcome

The outcomes from this initiative will be significant and will play out over coming years as the WA Department of Fisheries systematically moves through the application of the framework in other regions of WA. The overall outcomes from this investment include:

1. Review of the State's fisheries management system to ensure that governance structures are appropriate to consider all fishery and ecosystem risks;
2. Better alignment between the fisheries management and regional marine planning processes;
3. More efficient allocation of resources to high priority fisheries related issues;
4. Provision of a framework that can be extended seamlessly beyond EBFM to also deal with non-fisheries risks (i.e. Ecosystem Based Management, EBM);
5. Improved stakeholder engagement through participation in the risk-assessment processes and prioritisation exercises; and
6. Improved annual reporting to Parliament and Government on the management of the State's fisheries and aquatic resources through the use of the EBFM framework.

SUMMARY OF EBFM PROCESS

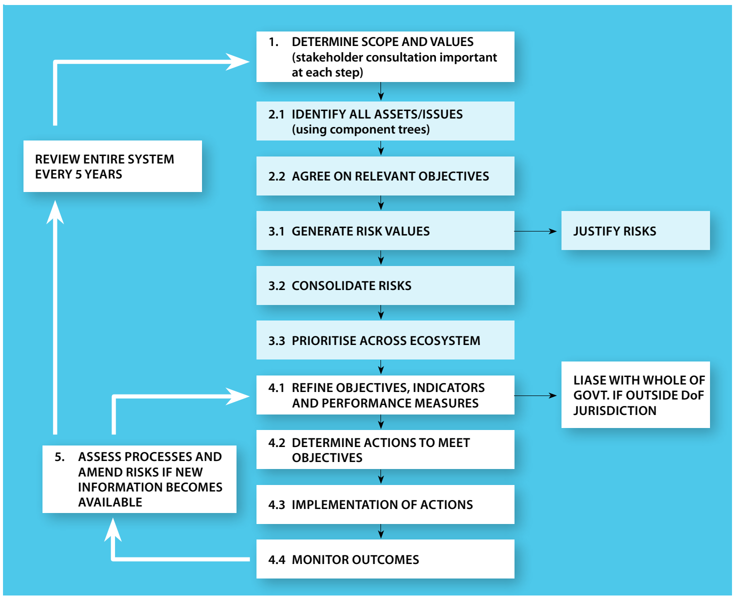


Fig 23 Flowchart of EBFM Process

4.3.2 Other Fisheries Related Research

Other fisheries related research was focused on specific management issues in support of EBFM. Outcomes from this research includes:

- Confirmation of qualitative modelling as an effective tool in the development of the EBFM approach for addressing the issue of recreational fisher behaviour and for understanding the key drivers in the assessment of the health of estuaries in the South West of WA, particularly the Peel/Harvey Estuary (see Box A).
- Confirmation that rock lobster fishing and changes in population density has no significant effect on the overall community structure in the habitats that support lobster populations in shallow water. For deeper water habitats that support lobster populations, maps and data have been generated for a closed reference area off the mid-west coast thereby providing a baseline against which to measure future change. A number of species in this deepwater ecosystem (small fish and crustaceans) have been identified to provide indicators of change from rock lobster extraction and bait input respectively.
- Identification of effective methods to address socio-economic implications of fisheries management decisions. This research involved the design and implementation of the most comprehensive survey of recreational fishing ever undertaken in the State. A significant result is that satisfaction levels of recreational boat fishers did not reduce following the introduction in July 2009 of restrictions on the catch of iconic demersal scalefish species such as dhufish, bald-chin groper and pink snapper in the West Coast Bioregion (Fig 24). Overall there was a high degree of acceptance of the new management restrictions that were imposed to ensure long-term sustainability of stocks. The societal benefits of such sustainability measures will largely be realised by future generations, an outcome that the majority of current fishers appear to have accepted, despite initial reluctance on their part. This study showed that the fishing community can deal with a level of reduced personal benefit (i.e. lower individual catches) in the overall interests of ensuring sustainability of stocks in the future. Additionally, expenditure on recreational fishing was not affected by the changes in management arrangements. Subsequent surveys show that satisfaction with the overall fishing experience had increased since policy changes were enacted. However, the research also revealed that the restrictions had a significant effect on economics and use patterns of the charter fishing industry, forcing changes in the size of fleet, target species and areas of operation.
- Identification of indicator regions and robust indicator species for monitoring of change in fish biodiversity and habitats under climate change. This research supports the EBFM Framework, by validating the risk assessment of assets and assisting with changing risk profiles arising from change environmental conditions e.g. climate change effects. This research has identified that the abundance and distribution of some key taxa, including several types of alga (*Scytothalia dorycarpa* and 'brown foliose') and various sponges, change predictably along the regional

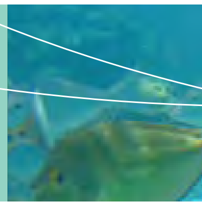
latitude/temperature gradient and may serve as effective indicators of future environmental change such as ocean warming. The use of canopy forming macroalgae as indicators of habitat change should be cost effective and reliable. Similarly robust indicators of fish biodiversity were also identified through the use of small-bodied species of both tropical and temperate fishes that vary in their abundance and distribution along the WA coast and with changes in temperature.

- Evaluation of the risks to the western rock lobster fishery from climate shift effects such as rising ocean temperatures. Biological parameters (e.g. reproduction, survival, growth to maturity) of western rock lobster were generally assumed to be fixed, but WAMSI research has changed this view. Climate change effects such as increasing water temperature may cause a decrease in size at maturity, a decrease in size of migrating lobsters and an increase in the abundance of undersized and legal size lobsters in deep water relative to shallow water. This is likely to lead to a shift in the fishery from shallow to deeper water in future years with significant implications for the fishery and its management. It will be important for fisheries managers to be able to predict with reasonable certainty any changes in abundance and distribution of western rock lobster, so that catch quotas or fishing effort can be adjusted in order to maintain a sustainable fishery.

- The development of quantitative methods to assess the status of the community structure, biodiversity and key habitats within each of the priority ecosystems within the West Coast Bioregion and, where possible, to discriminate the potential impact of each individual factor within the cumulative impacts of all fishing activities, climate shifts and other factors. The data on types and numbers of fish and benthic flora and fauna were collected using standard (e.g. baited underwater cameras, hand-hauled seine nets) and novel (precisely positionable underwater probes) approaches, in addition to undertaking further complex analyses of previously collected data (e.g. historical fisheries and oceanographic data, sea-floor mapping data). In the case of the Swan, Peel-Harvey and Leschenault estuaries, historical data on the composition of fish communities was used along with additional identical sampling to ascertain if there have been any major changes in the health of these systems. Iterative analyses on the various marine and estuarine data sets were completed to derive options for generating meaningful indices that could potentially be implemented for future assessment of the health of fish and benthic communities. A modest investment by WAMSI supported the collation and examination of all relevant data sets on environmental variables of possible relevance to fish stocks and ecosystems, with recruitment variability of western rock lobster a particular focus. The impact of climate change on the level and spatial distribution of rock lobster puerulus settlement, catchability of lobsters in traps, numbers of mature females moulting from setose to non-setose, growth rates, timing of moults and hence the timing of the peak catch rates, were assessed. Finally, a modelling exercise was undertaken to examine potential range shift of various fish species under the influence of predicted climate change impacts on the coast waters around Western Australia.

One of the benefits of an integrated research program and a collaborative culture, that has been the hallmark of WAMSI research over the past five years, is the enhanced ability to rapidly bring together key researchers from different institutions and disciplines to address complex problems. An example is the response to the major La Niña induced 'marine heatwave' experienced off the WA coast in early 2011. The Department of Fisheries WA was able to rapidly convene a workshop with experts from fisheries management, conservation ecology, physical oceanography and climatology to pool their knowledge in order to provide guidance to management agencies (see Box E "Marine Heatwave").

Fig 24 Iconic Demersal fish species l-r Bald-Chin Groper, Dhufish and Pink Snapper



Box E
Marine Heatwave off Western Australia 2010/11

Water temperatures off the south-western coast of Western Australia rose to unprecedented levels during February and March 2011, and this warming event has been termed a "marine heat wave". While surface temperatures were more than 3°C above the long-term monthly average over an extended area in February 2011, the temperature in some localised areas in coastal waters exceeded the long-term monthly average by 5°C for periods of a day or two in late February/early March (Fig 25). A scientific workshop on Thursday 5 May 2011 brought together key WAMSI and other researchers, as well as fisheries managers, to review the oceanic processes and biological/fisheries consequences of the heat wave. The workshop also provided an efficient means for capturing additional anecdotal information about the heatwave.

This heat wave, which coincided with an extremely strong La Niña event and a record strength Leeuwin Current, is viewed as a major temperature anomaly superimposed on the underlying long-term ocean-warming trend. While sudden changes in water temperature have been recorded in waters off the Western Australian coast in the past, there have been no previous records of such strongly elevated temperatures.

Biological effects reported to date include fish and invertebrate deaths, extensions and contractions in species distributions, variations in recruitment and growth-rates, impacts on trophic relationships and community structure, and variations in catch rates of exploited species. As such, the elevated water temperatures were viewed as resulting either in mortality or in a variety of "sub-lethal" effects, all of which can have either short or long-term implications.

These observed and expected biological consequences are based primarily on anecdotal information collected during or directly after the passage of the heat wave. However, as results from ongoing research and monitoring programs become available, a more comprehensive and considered view of the effects will be forthcoming in the form of peer-reviewed journal papers. While widespread mortality of fish and invertebrates were reported, none were shown to be attributable to disease. It appears that the incursions of large volumes of silt-laden water from river outflows into the adjacent coastal waters of the mid-west coast between Dongara and NW Cape following the passage of the tropical cyclone Bianca in late January are also likely to have contributed to the mortality experienced by the marine biota of that region.

Fisheries management responses to this event include review of management arrangements for fisheries affected by the warming e.g. Roe's abalone fishery and 2010 western rock lobster puerulus settlement.

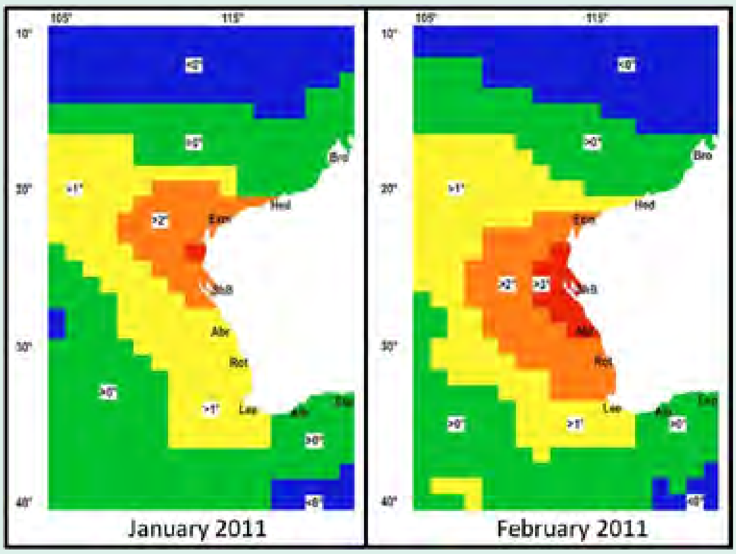


Fig 25 Monthly SST anomalies in the south-eastern Indian Ocean in January and February 2011 Each coloured block represents the difference between the monthly SST for that block and the long-term average for the month.

Red = > 3 °C anomaly;
Orange = 2 to 3 °C anomaly;
Yellow = 1 to 2 °C anomaly;
Green = 0 to 1 °C anomaly;
Blue = < 0 °C anomaly.

4.3.3 Biodiscovery in WA Marine Estate

The purpose of WAMSI investment in this sector was to establish a system for marine biodiscovery and biotechnology that enabled industry and government to capitalise on the uniqueness, endemism and profusion of the State's marine biodiversity e.g. deepwater sponges (Fig 26). The main hurdle limiting progress in the marine biotechnology sector has been a lack of a suitable legislative framework in WA to underpin security through benefit sharing in biodiscovery investment. The current regulatory regime provided little incentive to investment in the expensive process of detecting suitable compounds in natural products and taking them through to pharmaceutical or other applications. Allied to this was the need for a robust storage and control system that ensured the marine specimens were properly curated, stored and made available to accredited researchers.

Outcomes

New legislation has been drafted and a WA Bioprospecting Bill is expected to be introduced to the WA Parliament in early 2012. When enacted, this legislation will give much needed certainty to the management and investment in bioprospecting and research directed to discovery of new drugs or applications.

The establishment of a WA Marine Bioresources Library (WAMBL), under the control of the WA Museum, has been a major achievement. The WA Museum marine invertebrates collections database contains all details on provenance of the specimens in WAMBL, including species identification (Fig 27) and all collecting data, including georeferencing of locations and depths. This database provides vital information on where the species occur in the event that further collections of a particular species are necessary. Such collections are important in value adding to commercialisation potential as well as enhancing our knowledge of species. Protocols and a Material Transfer Agreement have been developed. These can be used for transfer of specimens or extracts for biodiscovery research consistent with international biodiscovery agreements.

Proof-of-concept analysis has shown the potential of WA's endemic marine-derived samples to lead to novel anti-cancer products. It has also clearly demonstrated the potential to discover and develop novel Quorum Quenching Compounds from marine bacteria. This indicates the potential for new natural products to be found from marine bacteria to address important industrial and medical issues, including antibiotic resistance.

The overall outcome of WAMSI investment in this area has been the establishment of a sound platform for future investment and research in biodiscovery and biotechnology.

Fig 26 Deep water sponge from WA

Fig 27 Identification of sponges

4.4 Data/Information Management and Visualisation Tools

A large amount of marine data has been collected by WAMSI projects. In the past, marine data has often not been catalogued, described or stored in an accessible repository. This makes discovery and re-use difficult, as it requires personal knowledge of the research and/or researcher.

WAMSI has created an enduring legacy of marine data management by making all WAMSI data discoverable and accessible through the WA Node of the Australian Ocean Data Network (AODN) via standardised metadata descriptions. WAMSI project agreements require metadata to be created i.e. a description of the data, where it is held and how to access it. All WAMSI data will be made public through WAMSI partner data centres or from iVEC via the WA Node of AODN after an embargo period of 12 – 18 months for researchers to publish their work.

This web-based portal is available to any research institution in Australia, or elsewhere in the world, to work on datasets that will add to global knowledge about marine environments; this should also encourage collaboration and new investment in WA marine research by other research institutions.

The main data and information collected under WAMSI is accessible through an online catalogue - the WA-AODN Metadata Entry and Search Tool (MEST). This is harvested by the central Australian Ocean Data Network MEST and then by the Australian National Data Service (ANDS) and Research Data Australia services.ands.org.au/home/orca/rda/ (Fig 28). ANDS optimises this information for search engine crawlers such as Google, allowing users to perform a 'Google search' to find marine data, without the need to be aware of specific marine data catalogues.

In addition, under WAMSI there have been significant improvements in the development of the Data Interrogation and Visualisation Environment (DIVE) tool which enables researchers and managers to assemble, overlay and visualise the wide array of spatial and temporal marine data sets collected in WAMSI (see software.cmar.csiro.au/www/en/software/dive.html) to access this tool.

There are many benefits in making marine data more discoverable and accessible:

- Results are publicly available and able to be verified, increasing transparency and making unsubstantiated challenges more difficult;
- Data from different disciplines, institutions and researchers can be applied more readily to complex problems;
- Most marine data is a snapshot in time and cannot be duplicated; repeating marine surveys to obtain comparable data at similar locations can be difficult and is expensive; conversely, duplication of effort can be avoided, saving money;
- New research can build on existing data sets enabling new insights and discoveries and the creation of time series to track trends; this should lead to additional publications and greater citation rate, and enhance grant applications;
- Funding agencies increasingly require research data (raw and processed) to accompany articles submitted for publication or to be stored in appropriate repositories;
- The culture of transparency and data sharing will enhance greater collaboration and efficiencies; and
- Publicly funded data should be publicly and easily accessible for further research.

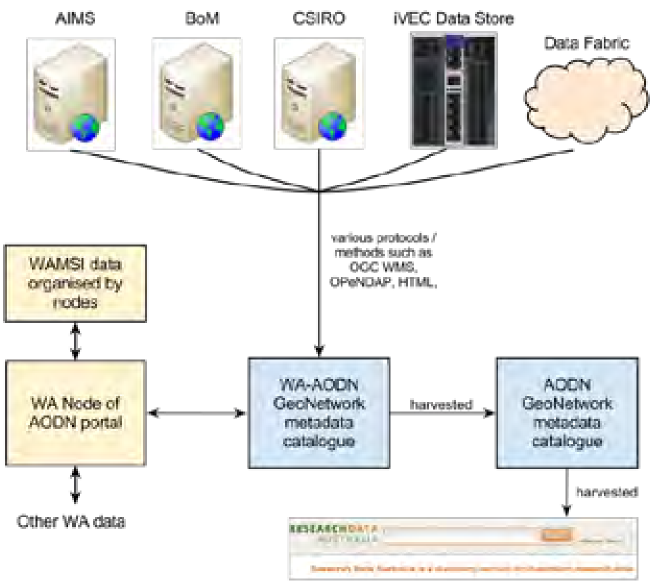


Fig 28 Example of WAMSI Data Repository Architecture

WAMSI has played a key role in encouraging the uptake of modern and efficient marine data management practices allowing data sharing and wider collaboration. Together with iVEC (the WA supercomputing centre), the Western Australian Satellite Technology and Applications Consortium and IMOS, WAMSI has hosted annual marine data management seminars based around the common need to develop the online discoverability and access tools needed for best-practice marine data management These partners also co-funded the employment of a dedicated Data Manager to support a range of WAMSI and non-WAMSI marine projects in WA.

WA was chosen as the first 'regional node' of the Australian Oceans Data Network (AODN) www.aodn.org.au, in part due to WAMSI's active role in promoting good data management practices, and building on earlier collaborations in WA such as Strategic Research Fund for the Marine Environment (SFRME) and North West Shelf Joint Environmental Management Study (NWSJEMS). The overall aim of the AODN node is to establish a sustainable marine data network through facilitating the storage, management, discovery and exposure of marine data in Western Australia whilst being part of the broader national interoperability approach. All sectors of the WA marine community (government, universities, private industry and community groups) will be engaged actively in this network.

4.5 Improving Predictions of Dredging Impacts

In early 2011 the State Government approved the allocation of some specific industry offsets funds to WAMSI to form a new Node in Strategic Dredging Science. This Node evolved as a strategic response to predictive and management uncertainties inherent in environmental impact assessment (EIA) of the growing number of large scale dredging operations in Western Australia associated with the current resources boom (Fig 29). The Node also addresses the specific regulatory requirements that apply to Woodside Energy Limited (WEL) for the development of its Pluto LNG plant in the Pilbara. A condition of approval for this project requires WEL to contribute funds towards 'improving capacity within government and the private sector to manage dredging impacts on tropical coral reef communities involving the collection of field and laboratory generated data'.

The initial research themes identified include:

1. Physical processes – including data acquisition to support models, pressure parameter measurements, modelling, model validation and remote sensing;
2. Corals and filter feeders – including identification of appropriate receptors and life history stages, biological response measurements and pressure response measurements; and
3. Primary producers (seagrasses/algae) including identification of appropriate receptors and lifehistory stages, biological response measurements and pressure response measurements

Expected outcomes from this research will be:

1. A greatly enhanced capability in WA government to undertake environmental impact assessments of dredging related development projects and to set appropriate environmental conditions for such projects;
2. Greater certainty and shorter timelines for environmental assessment processes for dredging projects, leading to reduced costs for both government and industry;
3. Greatly enhanced understanding of the environmental impacts of dredging in sensitive marine environments; and
4. New protocols and standards for water quality related to dredging and improved water quality in marine environments.

Fig 29 Trailing Suction Hopper Dredge

5.

RESEARCH QUALITY AND IMPACT

Research quality can be measured in a number of ways through recognition by peers, volume of outputs, reputation of journals publishing papers, prestigious awards to key researchers, citations, collaboration and co-funding. Quality control is a function of effective research project management systems.

Research impact is ultimately the degree to which the application of useful information in decisions produces effective outcomes for the State, and its sustainable use.

WA Government Evaluation Framework

This Section utilises the Evaluation Framework released by the Department of Commerce in May 2011. The Framework is intended for applications for future science and innovation grants commencing in 2012. The Framework uses the Inputs to Impacts model (Fig 30) to measure the economic, environmental, social and knowledge economy benefits of the proposal under review. WAMSI 1 research programs were prepared without the knowledge of the intended criteria for the Framework. To the extent possible this framework has been used to evaluate the outcomes and benefits of WAMSI 1 research, primarily as a qualitative exercise.

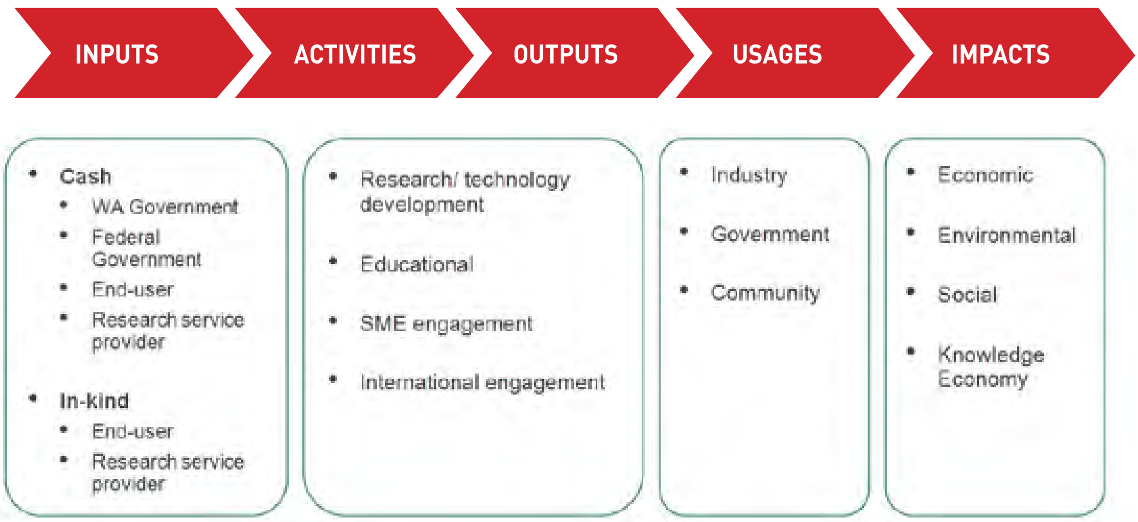


Fig 30 Inputs to Impacts model

The results below are presented using those components of the structure and key criteria from the WA Government Evaluation Framework, relevant to this report.

1. Strategic Alignment - Environment

WAMSI 1 research has addressed this key priority area for government through integrated research in marine and coastal sciences, climate science, fisheries science and social sciences under three broad science themes - ocean system forecasting, biodiversity conservation, and natural resource management and development.

2. Research Inputs

Inputs to WAMSI 1 over the past five years total $92.85 million in cash and in-kind support for the main programs, including the original State Government MRF grant of $21 million plus an additional $5.63 million in commissioned projects. WAMSI research projects have also generated additional direct grants to partners (e.g. additional FRDC grants to add to WAMSI fisheries-related projects) and complementary projects (e.g. the establishment of the Ningaloo Atlas through AIMS with funding from BHP-Billiton using datasets from WAMSI research). Table 2 shows the total resources (cash and in-kind) for WAMSI 2006-2011.

Research Program Resources 2006-2011 (A$ million)					
Type of Input	**State Govt**	**Cwlth Govt**	**Universities**	**Industry**	**Total**
Main Program					
Cash	21.96	12.58	6.50	0.07	41.11
In-kind	6.99	4.33	4.79	30.00	46.11
Total	**28.95**	**16.91**	**11.29**	**30.07**	**87.22**
Additional Projects					
Cash	3.60	0.99	0.00	1.04	5.63
In-kind					
Total	**3.60**	**0.99**	**0.00**	**1.04**	**5.63**
Total Resources	**32.55**	**17.90**	**11.29**	**31.11**	**92.85**

Table 2 Source: WAMSI projects agreements

3. Contribution to Innovation Systems Performance – Research Capacity and Skill Base

The main output indicators for research capacity and skill base include publications, citation indices of research partners, students supported (including completed theses) and additional research infrastructure generated by the programs. These are summarised in Table 3

Criteria	Description of WAMSI contribution
Publications by researchers participating in the proposal (number of peer reviewed papers, both journal and conference, publications by researchers participating in the proposal)[1,2]	• 150 Peer reviewed publications • 117 Conference proceedings • 8 Book chapters • 63 Technical Reports • 13 Theses completed or submitted
Number of fields (at 2-digit level), published by research partners, with higher than world average citation rate	• 9 Fields
Number of students completing higher degrees by research in Western Australia	• 34 PhD students supported by WAMSI
R&D infrastructure in WA (improving the standard of R&D infrastructure in WA)	• WAMSI research has been enhanced by the application of national research infrastructure to WA issues e.g. CSIRO and AIMS research facilitates and vessels, IMOS gliders. • WAMSI has facilitated related investment in marine science in WA e.g. Commonwealth funded Indian Ocean Marine Research Centre; relocation of CSIRO Wealth from Oceans Flagship headquarters from Sydney to Perth.

Table 3 – Outputs in Research Capacity and Skill Base

[1] further articles arising from WAMSI research 2006-2011 will be published over the coming 12 months or so.

[2] includes papers published, in press, submitted and accepted.

4. Contribution to Innovation Systems Performance – Business Innovation

Two partners from industry, Woodside Pty Ltd and BHP-Billiton, are foundation members of WAMSI and continue to contribute strongly to the research program. Woodside was an early partner with the UWA School of Environmental Systems Engineering in Project 6.2 Impact of tides and internal waves on offshore engineering. Woodside has also commissioned additional projects through WAMSI to address key marine conservation issues in the Browse Basin e.g. whale migration patterns. BHP-Billiton has funded the development of the Ningaloo Atlas through AIMS, using data sets from the WAMSI Ningaloo Research Program.

5. Contribution to Innovation Systems Performance – Links and Collaboration (other than between WAMSI partners)

Research undertaken by WAMSI partners has not only been highly collaborative and integrated, but has also enhanced existing or generated significant new linkages to national and international institutions. Particular areas of research collaboration have been in ocean dynamics, internal wave propagation, ocean glider technology and deployment for ocean shelf processes, coastal sea level rise, storm surge forecasting, seabed characterisation and coastal zone research. Significant national and international collaboration has occurred with the following institutions over the past five years:

National Collaborative Links

- Commonwealth Department of Climate Change and Energy Efficiency
- Antarctic Climate and Ecosystems Cooperative Research Centre
- Commonwealth Department of Environment, Water, Heritage and The Arts
- Commonwealth Department of Sustainability, Environment, Water, Parks and Communities
- University of New South Wales
- Geosciences Australia
- Marine National Facility
- Integrated Marine Observing System
- National Climate Change Adaptation Research Facility
- ANNIMS
- University of Tasmania
- Commonwealth ARC Program
- Caring for Country Program
- Net Conservation Benefits Program
- CERF/Census of Marine Life Program
- Eskitis Institute Queensland for Cell and Molecular Therapies
- Fisheries Research and Development Corporation

International Collaborative Links

- UN Food and Agriculture Organisation
- Massachusetts Institute of Technology, USA
- Oregon State University, USA
- Oklahoma State University
- Scripps Research Institute USA
- Stanford University USA
- Massachusetts Institute of Technology, USA
- US Naval Research Laboratory, Stennis Space Centre, Mississippi, USA
- National Oceanography Centre at University of Southampton, UK
- University of Seigen, Germany
- USA National Cancer Institute
- NASA JPL, USA
- NOAA PMEL, USA
- IFM-GEOMAR, Germany
- Chinese Academy of Sciences, China
- University of Hawaii, USA
- University of Tokyo, Japan

- Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences
- Intergovernmental Oceanographic Commission
- Wang Kuangcheng Education Fund of Hong Kong
- South China Sea Institute of Oceanology
- Chinese Academy of Sciences, Guangzhou, China
- Ocean University, Qingdao, China
- Institute of Oceanology, Qingdao, China
- Chinese Academy of Sciences, Qingdao, China
- CLIVAR Asia-Australia Panel
- CLIVAR Indian Ocean Panel

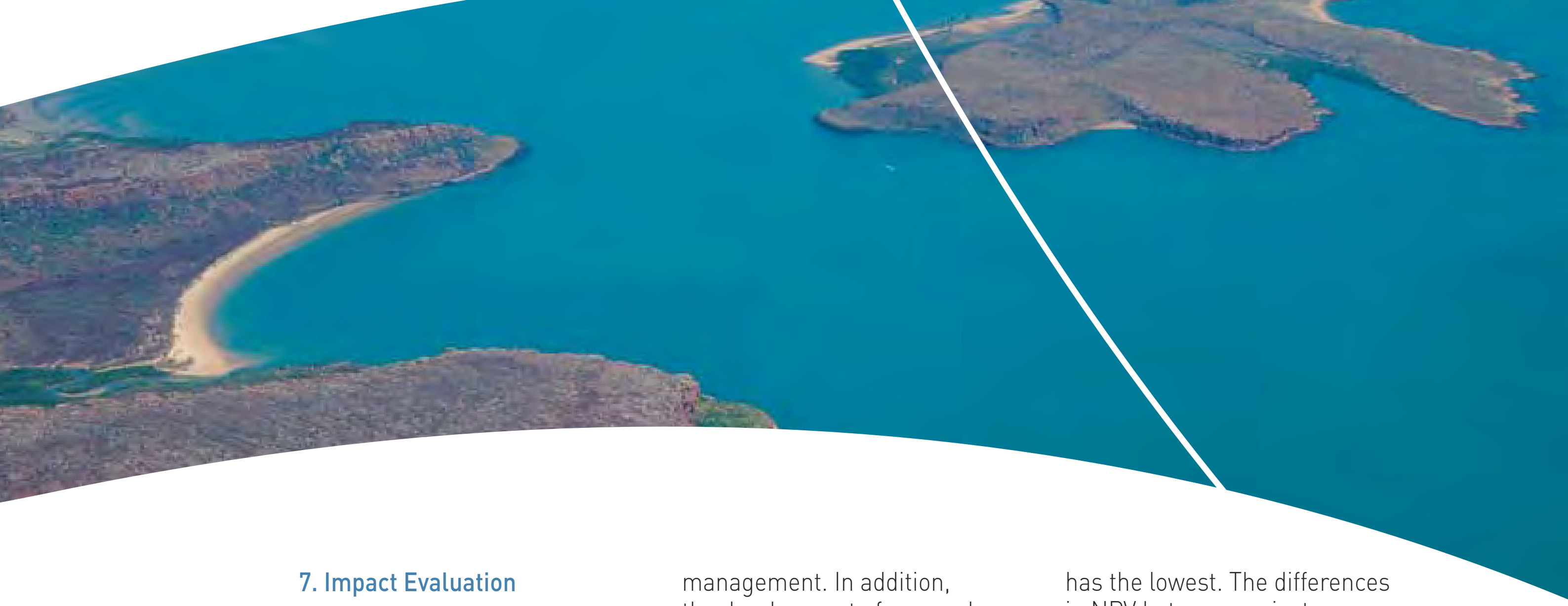
6. Research/technology development outputs (e.g. new processes and systems, products, models, software, policy/guidelines, standards methodology.)

The primary purpose of WAMSI research has been to address research needs for strategic management issues, rather than the development of new technology per se. The focus has been on generating new knowledge and understanding to improve decision making by industry and government. The research undertaken over the past five years has generally utilised existing models, software, techniques and technology as a basis for development and applications specific to WA issues. However significant benefits have been accrued through the adaptation of many existing models and other technology to the WA context.

Examples of these adaptations include:

- Improved development of the Data Interrogation and Visualisation Environment (DIVE) tool that enables researchers and managers to assemble, overlay and visualise a wide array of spatial and temporal marine data sets;
- The downscaling of BLUElink/BRAN/Xbeach models to develop hydrodynamic models at scales of metres e.g. at Marmion Marine Park;
- The adoption and refinement of the national climate model POAMA to derive a predictive scheme for Fremantle sea levels and a proxy index for the Leeuwin Current;
- The development of a range of biological and geochemical indicators for ecosystem health in coastal environments;
- The development of a map of mean sea level, astronomical tide, storm surge and wave climatology for WA;
- Qualitative and quantitative modelling of Peel/Harvey Inlet;
- Integration of ROMS (Regional Ocean Modelling System) and SUNTANS (Stanford Unstructured Adaptive Navier Stokes Solver) to develop models specific to predictions of ocean behaviour on the North West Shelf;
- The use of remote sensing, LIDAR and remote underwater video photography to gather data to characterise benthic habitats, often beyond the range of SCUBA diving;
- The use of underwater glider technology to gather data to characterise ocean conditions;
- The use of satellite tagging to monitor the behaviour of fish species;
- The application of Management Strategy Evaluation modelling to specific locations and conditions (e.g. Ningaloo Marine Park);
- The development of a Tourism Destination Model to assist planning for the Ningaloo Coast; and
- The development of a marine data management system that requires all WAMSI data to be discoverable and accessible through the WA Node of the Australian Ocean Data Network (AODN) via standardised metadata descriptions.

The most significant policy developments that are a direct result of WAMSI investment are firstly the adoption of Ecosystem Based Fisheries Management as the basis for fisheries management in the State and secondly the development of new draft legislation for regulation of biodiscovery and biotechnology in WA. A third example is the rapid generation of benthic habitat maps of the Kimberley coast as input to the government decision on the location of the Kimberley Hub gas processing precinct. In addition, the application of many existing policies and processes will be enhanced by the knowledge and understanding generated through WAMSI research e.g. for environmental impact assessment and for marine conservation and marine parks management.



7. Impact Evaluation

The impact of WAMSI research over the past five years in terms of economic, environmental, social and knowledge economy benefits are expected to be significant.

Economic benefits are expected through improved cost-effectiveness of fisheries and marine conservation management, and through improved engineering design criteria for undersea infrastructure. More efficient resource allocation decisions will accrue from the adoption of EBFM in fisheries management. Improved understanding of the role of the Leeuwin Current in recruitment of western rock lobster will aid the sustainable management of this valuable industry. Lower risks and costs should accrue in coastal planning through the improved understanding and modelling of climate variability and climate change effects on coastal structures. The knowledge from research at Ningaloo Marine Park will improve the planning and management of other marine reserves in the State. Future economic benefits are possible through biodiscovery utilising WA's unique marine organisms.

Environmental benefits are expected to be substantial through better understanding of the effects of human us on marine systems and better modelling of climate change effects on vulnerable marine systems and species.

Social benefits are expected through improved fisheries and marine conservation management. In addition, the development of research "social capital" through WAMSI collaborative research will be of benefit to future applied research effort in the State.

The knowledge economy will benefit from the adoption of modern and efficient marine data management practices allowing data sharing and wider collaboration utilising the data collected through WAMSI research.

8. Other Measures of Research Quality - Cost/Benefit Analysis

During 2011 WAMSI commissioned a benefit-cost analysis of two selected projects and a whole Node (A. Bathgate 2011). The three benefit cost analyses completed were:

1. Project 4.2. Assessment of marine communities and impact of anthropogenic influences,
2. Project 6.2 Impact of tides and internal waves on off-shore engineering,
3. Node 3. Managing and conserving the marine estate.

Three standard measures of benefits were used in this assessment: net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR). These were estimated from the expenditure and flow of benefits over time, discounted by the time value of money.

The results of this assessment showed that all the selected projects/programs are likely to achieve good returns to the investment in time. Node 3 has the highest net present value of around $61m over the timeframe of the analysis, whilst Project 4.2 has the lowest. The differences in NPV between projects are largely a reflection of the total expenditure. The benefit-cost ratios were similar for all projects but there were large differences in the internal rate of return. The differences in IRR were largely due to the assumed lags until benefits accrued to the investments. A shorter lag results in a higher IRR, as shown for Project 6.2.

	Project 4.2	Project 6.2	Node 3
PV benefits	$12.0m	$22.1m	$75.3m
PV Costs	$2.5m	$5.5m	$13.3m
NPV	$9.5m	$16.6m	$61.9m
BCR	4.9	4.0	5.6
IRR	12.6%	65%	9.8%

In summary, the assessment concluded that projects 4.2 and 6.2 each had a significant private benefit (to fisheries and oil and gas industries respectively) but that there was also likely to be significant public benefits from these projects arising from better fisheries and marine conservation management. However the extent of these public benefits was more speculative. The benefits from Node 3 research were seen to be primarily of a public good nature.

Source: Bathgate A. 2011 Assessment of the economic benefits of research and development being undertaken by partners of the Western Australian Marine Science Institution.

6.

EMERGING ISSUES IN MARINE SCIENCE

WAMSI is an excellent model for governance and coordination of collaborative, effective and efficient delivery of research outcomes for government and industry. The original State Government investment has leveraged multiple additional grants and investment. The research has been cost-effective and transparent and the legacy of data, marine specimens and analytical and predictive tools will benefit the State for many years, particularly through the "research social capital" and enhanced marine science capability that has been generated.

The type of strategic, integrated research able to be undertaken through WAMSI as a coordinating institution would not have been achieved through normal market forces or private sector research and development. It is only through organisations like WAMSI that the complex State and national strategic marine science priorities can be addressed effectively and efficiently.

WAMSI 2006-2011 has made significant progress in improving our understanding of the WA marine environment, human uses and values and the potential effects of climate change on the coastal and marine environment. Nevertheless many uncertainties remain and there are significant gaps in our knowledge. WA has Australia's longest coastline and an internationally significant coastal and fishing zone that contains temperate and tropical ecosystems on the continental shelf and in deep water. There are still significant gaps in the knowledge needed to address the State Government's high level policy objectives for marine science, marine conservation and marine natural resource management, including strategic marine science capability and consequences and impacts of climate change. Initial downscaling of large regional climate models to WA developed under WAMSI 1 needs further refinement to improve forecasting and predictions of natural climate variability and the effects of climate change. Better predictive understanding is needed of the cumulative impacts of development and usage on the coastal and marine environment of Western Australia.

The intensity of marine research undertaken in Ningaloo Marine Park and in the Southwest Bioregion needs to be repeated in other important marine environments e.g. Shark Bay, Pilbara coast and South coast of WA, in order to ensure sustainable use and wise management of the State's natural resources. Understanding and managing human impacts on iconic marine wildlife such as whales, sharks, dugongs, turtles, sea lions and in-shore dolphins remains a high focus public issue.

The Commonwealth Government's 2011 Strategic Roadmap for Australian Research Infrastructure includes priorities for research into the marine environment and biological collections and biobanks. Alignment with these priorities will be important to retain the commitment of Commonwealth publically funded research agencies (PFRAs) such as AIMS and CSIRO to WA marine issues. Serious gaps remain in the sciences particularly in the disciplines of taxonomy and mathematics. Science leadership is another skill base that needs boosting. Institutions like WAMSI can contribute significantly to bridging some of these gaps through its proven governance and integrated collaborative science systems and culture.

The WAMSI 2 bid to continue research in 2012-2016 seeks to address some of the gaps in knowledge. The Strategic Dredging Science program will be funded through industry offset funds and the Kimberley Marine Science program will be funded directly by government. Further integrated research programs are being developed to provide relevant information to address the complex, multi-faceted issues facing government and industry over the next decade.

Figures

Fig 1 Western Australia showing its marine estate

Image: Department of Sustainability, Environment, Water, Population and Communities (SEWPaC)

Fig 3 WAMSI Governance and Operations
Image: WAMSI

Fig 4 Example of nested models showing current speeds. Higher resolution generates higher model speeds.
Images: Dirk Slawinski, CSIRO

Fig 5 Slocum Glider
Image: Glenn Hyndes, ECU

Fig 6 Representation of Dense Shelf Water Cascade off Two Rocks near Perth
Image: Thisara Welhena, UWA

Fig 7 Comparison of present day sea level with possible flooding areas under different climate change induced sea level rise.
Image: Ivan Haigh, UWA

Fig 8a Yanchep Lagoon and Coastal infrastructure
Image left: Shari Gallop, UWA

Fig 8b Aerial Image of shoreline
Image Right: Reproduced by permission of the Western Australian Land Information Authority, CL48-2011

Fig 9 Graphic representation of Internal Wave at Browse Basin
Image: Greg Ivey, UWA

Fig 10a and 10b North Rankin Drilling Platform
Images: Greg Ivey, UWA

Fig 11 BLUElink ReANalysis (BRAN), Data assimilating 10 Km resolution
Image: Dirk Slawinski, CSIRO

Fig 12a Ocean Circulation Pattern off Western Australia
Image: Department of Sustainability, Environment, Water, Population and Communities (SEWPaC)

Fig 12b Leeuwin Current and Eddy
Image: Department of Fisheries

Fig 13 Model showing Nutrient Entrainment by Leeuwin Current
Image Right: Reprinted from "Progress in Oceanography", Thompson, P.A., et al. Nutrients in an oligotrophic boundary current: Evidence of a new role for the Leeuwin Current. Prog. Oceanogr. (2011), doi:10.1016/j.pocean.2011.02.011, with permission from Elsevier.

Fig 14 Larval Retention Areas and Scallop Fishing Grounds
Image: Reprinted from "Retention and dispersal of shelf waters influenced by interactions of ocean boundary current and coastal geography", Ming Feng, et al. Marine and Freshwater Research, 2010, 61, 1259–1267, CSIRO.

Fig 15 Map of Ningaloo Marine Park
Image: Department of Environment and Conservation

Fig 16 Ningaloo Coast World Heritage Area boundary, including Ningaloo Marine Park.
Image: Department of Fisheries WA

Fig 17a Spatial models and their outputs from AIMS
Image: Ben Radford, AIMS

Fig 17b Images of Habitat Mapping using Remote Sensing, and Underwater Video
Image: Kobryn, H.T., Wouters, K. and Beckley, L.E. 2011, Habitats and biodiversity of the Ningaloo Reef lagoon and adjacent coastal areas with hyperspectral imagery. Ningaloo Collaboration Cluster Final Report 1b, May 2011 CSIRO, p228.

Fig 18 Model of the Evaluation Strategy Process
Image: Fabio Boschetti, CSIRO

Fig 19 Spangled Emperor
Image: John E. Randall

Fig 20 Marmion Marine Park off Perth
Image: Graham Symonds, CSIRO

Fig 21 Aerial image of Kimberley Coast
Image: Kimberley from Space, Landgate

Fig 22 "Turning of the Tide"
Image: WAMSI

Fig 23 Flowchart of EBFM Process
Image: Rick Fletcher, Department of Fisheries

Fig 24-1.Bald-chin Groper, 24-2.Dhufish and 24-3.Pink Snapper
Images: 1& 2 T Carter, 3 G Yearsley, CSIRO copyright

Fig 25 Heat wave Sea Surface Temperatures
Image: Reprinted from "The 'marine heat wave' off Western Australia during the summer of 2010/11",, Pearce A, Lenanton R, Jackson G, Moore J, Feng M and Gaughan D (2011), Department of Fisheries WA

Fig 26 Deep water sponges from WA
Image: Clay Bryce, WA Museum

Fig 27 Identification of Sponges
Image: WAMSI

Fig 28 Example of WAMSI Data Repository Architecture
Image: Luke Edwards, iVEC

Fig 29 Trailing Suction Hopper Dredge
Image: Cam Sim, Office of the Environmental Protection Authority

Fig 30 Inputs to Impacts model
Image: Simon Aarons, Department of Commerce

Appendix 1 Glossary

AATAMS Australian Animal Tagging and Monitoring System

AIMS Australian Institute of Marine Science

ANNIMS Australian National Network in Marine Science

AODN Australian Oceans Data Network

BRUVs Baited Remote Underwater Video

C-Reefs Census of Coral Reef Ecosystems

CERF Commonwealth Environment Research Facilities

CRC Cooperative Research Centre

CUT Curtin University of Technology

DEC Department of Environment and Conservation

EBFM Ecosystem Based Fisheries Management

EBM Ecosystem Based Management

ECU Edith Cowan University

EIA Environmental Impact Assessment

ELFSim Effects of Line Fishing Simulation

ENSO El Niño Southern Oscillation

ESD Ecologically Sustainable Development

FRDC Fisheries Research and Development Corporation

IFM-GEOMAR the Leibniz Institute of Marine Sciences, Germany

IMOS Integrated Marine Observing System

IOD Indian Ocean Dipole

LNG Liquefied Natural Gas

MRF Major Research Facility

MSE Management Strategy Evaluation

NASA National Aeronautics and Space Administration (USA)

NOAA National Oceanic and Atmospheric Administration (USA)

PFRA Publicly Funded Research Agency

POAMA Predictive Ocean Atmosphere Model for Australia

ROMS Regional Ocean Modelling System

SRFME Strategic Research Program for the Marine Environment

SUNTANS Stanford Unstructured Adaptive Navier Stokes Solver

UWA University of Western Australia

WAGOOS Western Australian Global Ocean Observing System

WAMBL Western Australian Marine Biological Resources Library

WEL Woodside Energy Ltd

Appendix 2 Acknowledgements

Governors

(As at end of 2011)

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Western Australian Global Ocean Observing Systems

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Dr Andrew Johnson
CSIRO

Mr Alec Coles
Western Australian Museum

Mr Kim Taylor
Office of the Environmental Protection Authority

Board Members

(As at end of 2011)

Dr Peter Rogers
Western Australian Marine Science Institution (Independent Chair)

Dr Jamie Oliver
Australian Institute of Marine Science

Dr Tom Hatton
CSIRO Wealth from Oceans Flagship

Mr Keiran McNamara
Department of Environment and Conservation

Mr Stuart Smith
Department of Fisheries WA

Professor Alistar Robertson
The University of Western Australia

Mr Charles Thorn
Curtin University of Technology

Mr Peter Millington
ChemCentre

Dr Steve Blake
WAMSI (CEO)

WAMSI Committee Members

(As at end of 2011)

Dr Bernard Bowen
Independent Chairman

Dr Peter Rogers
WAMSI Chairman

Dr Tom Hatton
CSIRO Wealth from Oceans Flagship

Mr Keiran McNamara
Department of Environment and Conservation

Dr Ian Poiner
Australian Institute of Marine Science

Mr Bruno Mezzatesta
Department of Fisheries WA

Mr Peter Millington
ChemCentre

Ms Denise McComish
KPMG

Dr Wally Cox
Chairman, WAMSI R&D Committee

Ms Diana Jones
Western Australian Museum

Node Leaders (2006 - 2011)

WAMSI Node 1 Leader

Dr John Keesing
CSIRO Wealth from Oceans Flagship

WAMSI Node 2 Leader

Dr Ming Feng
CSIRO Wealth from Oceans Flagship

Dr Bryson Bates (2007 - 2008)
CSIRO Wealth from Oceans Flagship

Dr Gary Meyers (2006 - 2007)
CSIRO Wealth from Oceans Flagship

WAMSI Node 3 Leader

Dr Chris Simpson
Department of Environment and Conservation

WAMSI Node 4 Leader

Dr Rick Fletcher
Department of Fisheries WA

WAMSI Node 5 Leader

Mr Howard Shawcross
Department of Fisheries WA

Mr Jason Froud (2009 - 2011)
Department of Fisheries WA

Dr Fiona Vom Berg (2008 - 2009)
Department of Fisheries WA

Dr Chris Battershill (2006 - 2008)
Australian Institute of Marine Science

WAMSI Node 6 Leaders

Prof. Greg Ivey

Prof. Chari Pattiaratchi
(Deputy-Node Leader 2006 - 2011)
University of Western Australia

WAMSI Node 7 Leader

Dredging Science

Dr Ross Jones
Australian Institute of Marine Science

Dredging Policy

Dr Ray Masini
Office of the Environmental Protection Authority

Project Leaders (2006 – 2011)

WAMSI Project 1.1 & 1.2 Leader

Dr John Keesing
CSIRO Wealth from Oceans Flagship

WAMSI Project 1.3 Leader

Dr Gary Fry
CSIRO Wealth from Oceans Flagship

WAMSI Project 1.4 Leader

Dr Andrew Heyward
Australian Institute of Marine Science

WAMSI Project 2.1 Leader

Dr Harry Hendon
Bureau of Meteorology

WAMSI Project 2.2 Leader

Dr Ming Feng
CSIRO Wealth from Oceans Flagship

WAMSI Project 2.3 Leader

Dr Richard Brinkman
Australian Institute of Marine Science

WAMSI Project Leader 3.1

Dr Andrew Heyward
Australian Institute of Marine Science

WAMSI Project 3.2 Leader

Dr Russ Babcock
CSIRO Wealth from Oceans Flagship

WAMSI Project 3.4 & 3.10 Leader

Associate Professor Lindsay Collins
Curtin University of Technology

WAMSI Project 3.5 Leader

Professor Chari Pattiaratchi
University of Western Australia

WAMSI Project 3.6 Leader

Dr Chris Simpson
Department of Environment and Conservation

WAMSI Project 3.7 Leader

Dr Chris Simpson
Department of Environment and Conservation

Dr Glenn Hyndes
Edith Cowan University

Professor Paul Lavery
Edith Cowan University

WAMSI Project 3.8 Leader

Dr Timothy Skewes
CSIRO, Wealth from Oceans Flagship

WAMSI Project 3.9 Leader

Dr Kelly Waples
Department of Environment and Conservation

WAMSI Project 4.1 Leader

Dr Dan Gaughan
Department of Fisheries WA

WAMSI Project 4.2 Leader

Associate Professor Euan Harvey
University of Western Australia

WAMSI Project 4.3 Leader

Professor Neil Loneragan
Murdoch University

Dr Lynda Bellchambers
Murdoch University

WAMSI Project 4.4 Leader

Dr Brett Molony
Department of Fisheries WA

Dr Steve Newman
Department of Fisheries WA

WAMSI Project 4.5 Leader

Dr Malcolm Tull
Murdoch University

WAMSI Project 5.1 Leader

Dr Jane Fromont
Western Australian Museum

Ms Elizabeth Evans-Illidge
Australian Institute of Marine Science

WAMSI Project 5.2 Leader

Prof. Peter Leedman
Centre for Medical Research

WAMSI Projects 5.4 Leader

Dr David Sutton
University of Western Australia

WAMSI Project Leader 6.1 & 6.3

Professor Chari Pattiaratchi
University of Western Australia

WAMSI Project Leader 6.2

Professor Greg Ivey
University of Western Australia

Science Coordinators

Dr Cam Sim
Office of the Environmental Protection Authority

Dr Kelly Waples
Department of Environment and Conservation

Ms Selina Cranley
Department of Fisheries WA

Students

(WAMSI top up scholarships)

Abbie McCartney - UWA
Adam Gartner- ECU
Ben Fitzpatrick - UWA
Cecile Rousseaux - UWA
Christopher Hallet- Murdoch University
David Holliday - Murdoch University
David Rivers - UWA
Emily Twiggs - Curtin University of Technology
Frazer McGregor- Murdoch University
Janja Ceh - Murdoch University
Miles Parsons - Curtin University of Technology
Saskia Hinrichs - UWA
Sarah Fretzer- Murdoch University
Soheila Taebi - UWA
Thea Linke - Murdoch University
Thisara Welhena - UWA
Kristel Wenziker - Murdoch University

Students also supported by WAMSI funding

Alexis Espinosa - UWA
Alexandra Stevens - Curtin University of Technology
Charulata Singh - ECU
Connor Mines - UWA
Cynthia Bluteau - UWA
Dani Barrington - UWA
Deanna Wilson - Curtin University of Technology
Eloise Brown - UWA
Fiona Patterson - UWA
Kenny Lim - UWA
Matt Rayson - UWA
Natalie Millar - Murdoch University
Paul van Gastel - UWA
Shahab Hosseini - UWA
Sharon Yeo - Murdoch University
Thibaut de Bettignies - ECU
Tien Lei - UWA

WAMSI HQ Staff

Dr Steve Blake 2006 - 2011 [Ongoing]
Ms Linda McGowan 2007 - 2011 [Ongoing]
Mr Luke Edwards 2008 - 2011 [Ongoing]
Mr Michael D'Silva 2011 [Ongoing]
Ms Lynne Stephenson 2007 - 2011
Ms Sue McKenna 2008 - 2011
Ms Jill Stajduhar 2007 - 2007
Ms Michelle Tarling 2006 - 2007
Ms Shelley McAlpine 2005 - 2006

Background Images

Sue Morrison - WA Museum
Peter Strain - Broome Picture Company
Mat Vanderklift - CSIRO
Russ Babcock - CSIRO
Clay Bryce - WA Museum

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