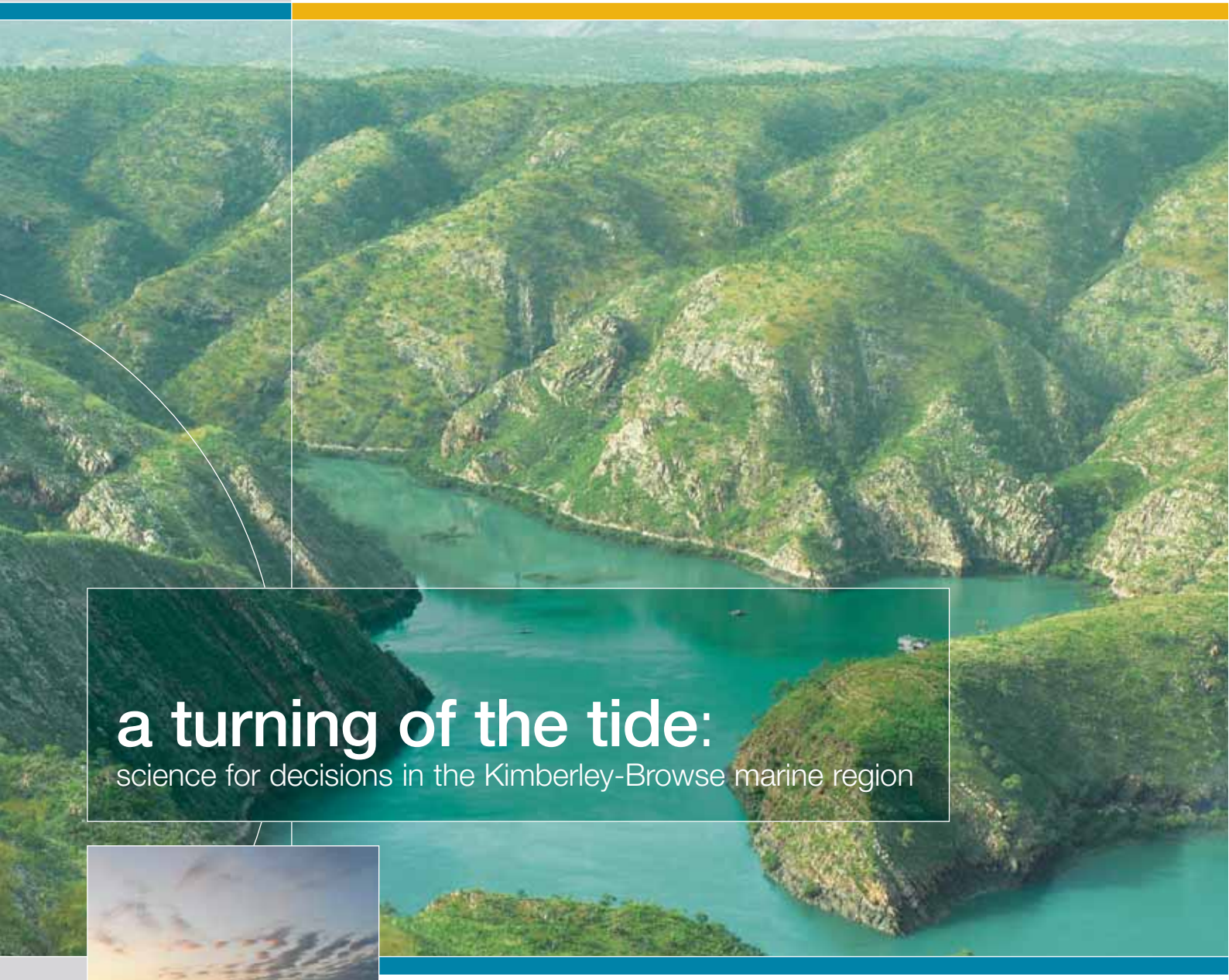
western australian
marine science institution



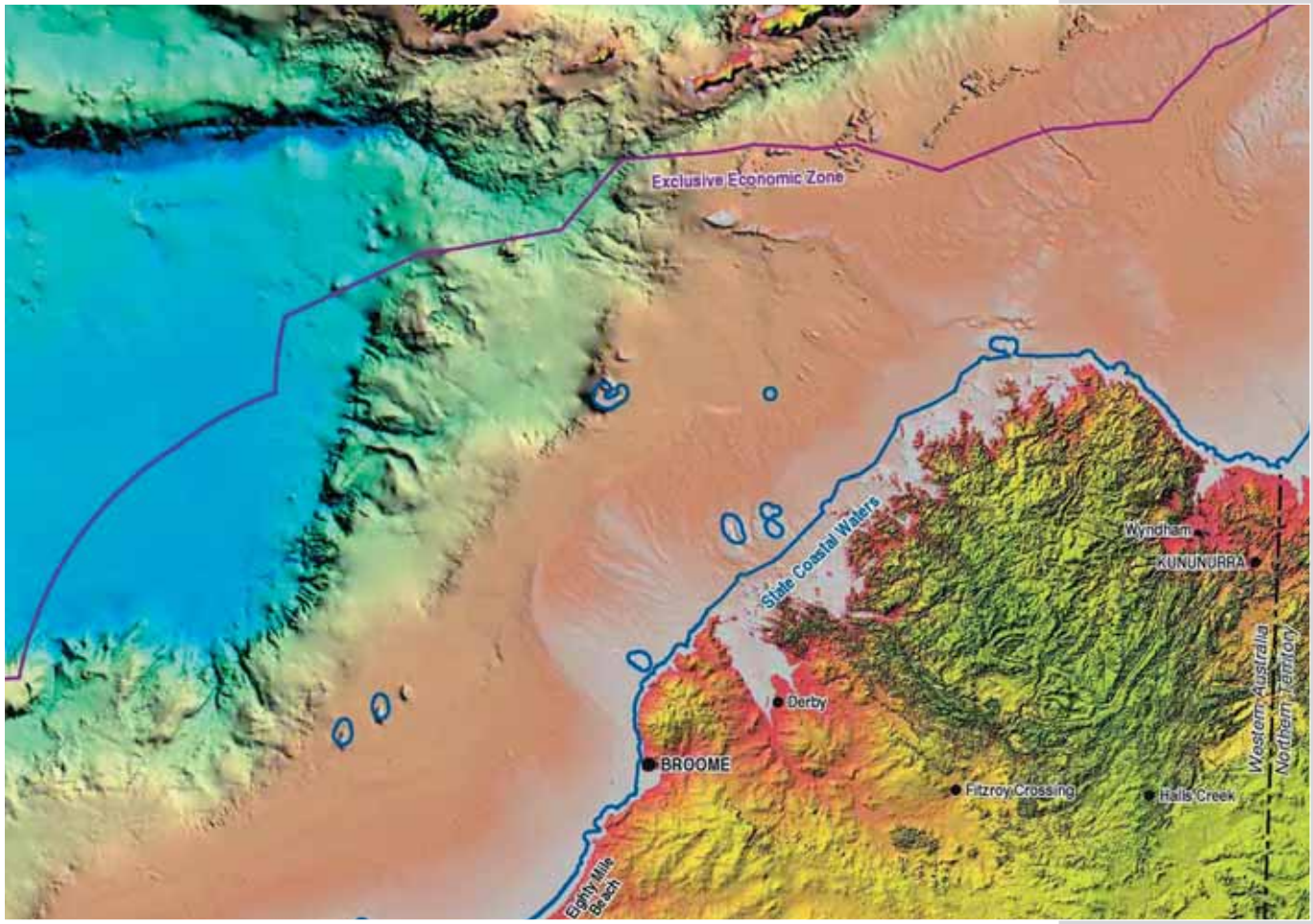
a turning of the tide:

science for decisions in the Kimberley-Browse marine region

A Western Australian Marine Science Institution (WAMSI) initiative

Prepared for WAMSI by **Professor Mike Wood**, School of Business, University of Notre Dame Australia and **Dr Des Mills**, Des Mills Marine Environmental Reviews

August 2008



Location map courtesy of Geoscience Australia.

Camden Sound.

Kimberley island and reef.

Photos – Dr Steve Blake

a turning of the tide:

Science for decisions in the Kimberley-Browse marine region

a WAMSI initiative

Prepared for the Western Australian Marine Science Institution (WAMSI)

by

Professor Mike Wood, School of Business, University of Notre Dame Australia

Dr Des Mills, Des Mills Marine Environmental Reviews

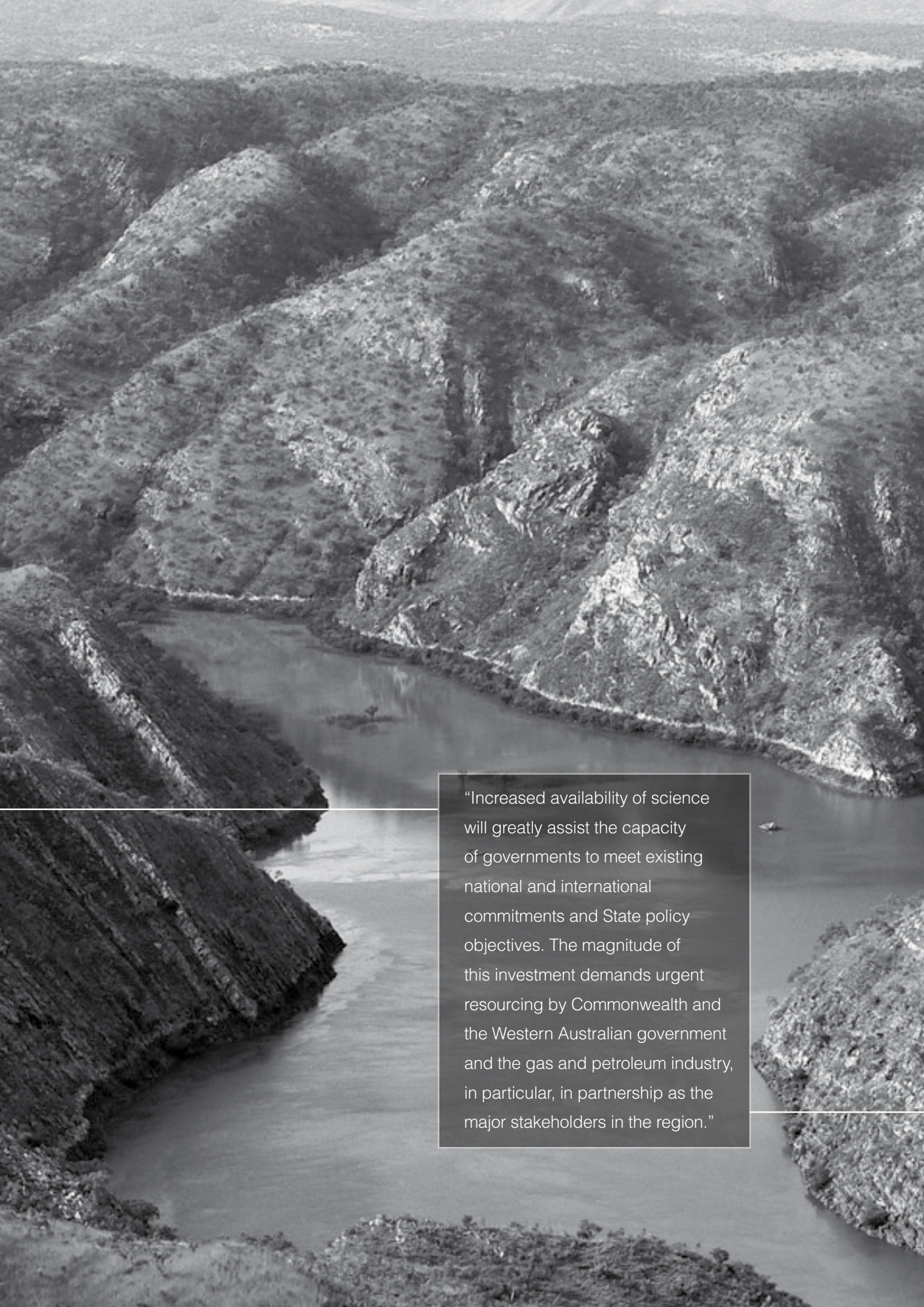
August 2008

Photographs: **Dr Steve Blake**, WAMSI

western australian
marine science institution

table of contents

list of tables



"Increased availability of science will greatly assist the capacity of governments to meet existing national and international commitments and State policy objectives. The magnitude of this investment demands urgent resourcing by Commonwealth and the Western Australian government and the gas and petroleum industry, in particular, in partnership as the major stakeholders in the region."

foreword

This report was commissioned by the Western Australian Marine Science Institution (WAMSI) in December 2007 following its decision to investigate the priority for marine science research work in the Kimberley region. Membership of the WAMSI Board is shown in Appendix 1.

The report was to provide WAMSI with an assessment of the state of strategic marine science in the Kimberley and offshore Browse Basin, and with a business case for the allocation of resources for science that would assist private sector, public sector and Indigenous decision-makers working in the region. This report provides the business case and the major points from the science case. The full text of the science case can be found in Appendix 2.

Stakeholders from the public and private sectors, the Indigenous people and not-for-profit organisations face extraordinary challenges. The Kimberley-Browse region is considered to have retained a very high degree of ecological integrity compared with other large tropical marine ecosystems of the world because of its remoteness and low level of past usage. Human activities in the region are increasing and now are on the threshold of rapid acceleration. International, Commonwealth and State interest and activity is growing and recent research into both Indigenous culture and life in the region and tourism serve to emphasise the challenges faced by decision-makers.

WAMSI is an unincorporated joint venture of 16 research member partners. Its formation and funding was announced in May 2005 when the then Science and Environment Minister, Dr Judy Edwards, said the government was "making a long-term commitment to build a world class marine science capacity that could help unlock the economic benefits that the marine environment could provide while ensuring that the marine environment was protected now and for future generations." (Press statement 5 June 2005)

WAMSI was launched in May 2007 and aims to strengthen the coordination and capacity of marine science in Western Australia, transferring the results of research into outcomes that deliver economic, environmental and social benefits to the State. WAMSI evolved from a commitment by government to fund strategic marine science initiatives. In its short life, it has been successful in drawing together scientists from the public and private sectors, from across Commonwealth and State boundaries and from across disciplines to work on strategic projects. WAMSI conducts innovative research in ocean systems forecasting, biodiversity conservation and natural resources management. This research advances understanding of Western Australia's unique marine ecosystems and how they can be sustainably used and managed for the benefit of current and future generations.

A Kimberley-Browse Marine Science policy summit, held at the University of Western Australia in March 2008, drew together policy-makers, scientists, users, local communities and not-for-profit organisations, representatives from the Commonwealth and State governments, the private sector and the four public universities in WA. This WAMSI initiative exemplified its role as a strategy-focused and coordinating organisation.

Related consultations held with over 50 people covered the same multi-jurisdictional and multi-disciplinary landscape. A representative stakeholder reference group established by WAMSI advised the consultants on drafts of the marine science case and the associated business case. The consultants also had the benefit of several meetings with leaders of WAMSI's six research nodes and interviews with senior staff in the Commonwealth and State governments. The consultants wish to thank all those who contributed time, ideas and disciplined analysis to this project.

The consultants referred to international, national and State research during the project. Though WAMSI has two leading private sector members (Woodside Energy and BHP Billiton Petroleum), funds for this project were drawn from the State government's five-year funding of the organisation and contributions from publicly-funded WAMSI members.

Professor Mike Wood, School of Business, University of Notre Dame Australia

Dr Des Mills, Des Mills Marine Environmental Reviews

"Public and private economic benefits flow from marine science research. Its absence can impair decision-making by stakeholders to the serious detriment of the environment, economic, social and cultural values of the region."

executive summary

It is rare for leaders to face decisions about the future as complex as those involving the cultural, environmental, economic and social values in the Kimberley. Current needs for energy and food and the development of existing uses challenge leadership to balance these within an awesome natural environment inhabited by Indigenous people for thousands of years.

Decision-makers and stakeholders with government responsibilities, and cultural and commercial interests in the Kimberley marine and offshore Browse Basin region of Western Australia urgently need a major infusion of about $110m over the next seven years to provide a commensurate level of science, adequate to support implementation of recent government decisions and to inform and underpin the significant decisions stakeholders face in years to come. Increased availability of science will greatly assist the capacity of governments to meet existing national and international commitments and State policy objectives. The magnitude of this investment demands urgent resourcing by the Commonwealth and the Western Australian governments and the gas and petroleum industry, in particular, in partnership as the major stakeholders in the region.

This report makes recommendations for new investments in marine science that are drawn from the accompanying science case. The science case is at Appendix 2 and its recommendations can also be found beneath the recommendations for resources and action. The recommendations for resources and action have their derivation in the business case and knowledge drawn from discussions with government officials, science leaders and non government organisations.

The report describes the region, its values, resources, people and stakeholders prior to discussing the opportunities and needs now surfacing in the context of rapid change. It examines the major regional issues and human uses, noting that there are significant and targeted information needs to support the achievement of government objectives and the goals of stakeholders. The report demonstrates that the marine science knowledge of the region must catch up with the requirements of policy makers and managers for better science to support better decisions, and then distills the main points of the science case. The resources needed to underpin the necessary strategic marine science conclude the report.

Public and private economic benefits flow from marine science research. Its absence can impair decision-making by stakeholders to the serious detriment of the environmental, economic, social and cultural values of the region. The risks for decision-makers of not having sufficient and reliable data on which to consider their decisions can be substantial, particularly when the data are as sparse as they are in the Kimberley-Browse marine region. For example, the Environmental Protection Authority makes recommendations which, when adopted, may have legally-binding conditions. It needs to have a high level of confidence in the science about risks and impacts when assessing development proposals.

Without this level of confidence, there is a high probability that decisions will have short time horizons, be costly and iterative as previously unknown problems needing control emerge. There are significant benefits for stakeholders if finer scale science in high priority areas is undertaken in the context of regional science knowledge. This improves interpretation and enables all proponents to draw upon the body of regional science as a significant one-off cost thereby reducing overall costs and risks to the community. The costs of unnecessary delays in development decisions, conflict, loss of confidence in public institutions and community dissatisfaction can be greatly assisted by all relevant stakeholders together contributing a higher level of science understanding to leaders and decision-makers. This research needs to be regional as well as location-specific to enable decision-makers to consider the regional significance of their decisions.

The Kimberley-Browse Marine Region – Focus of Interest

The unparalleled interest in the Kimberley, interest in conserving its values and in developing LNG as well as the task of the ongoing management of its marine resources underpins the need for significant investment in strategic marine science now.

Stakeholders want discoveries that allow the delivery of results in the short-term. They need sustained research that stays current and relevant to emerging regional issues and maintains currency and relevance to the big regional issues and major management tasks. Leaders have ahead of them tasks to meet Australia's international obligations; inform Commonwealth and State initiatives for climate change adaptation in and beyond the region; maintain biodiversity; provide certainty in the future use of resources; develop management plans in coastal and off-shore waters; and support programs aimed at security, energy security, bio-security, fishing, tourism and marine emergencies. The Interim Report of the Northern Development Task Force (June 2008) points to the issues seen as important by stakeholders. Two other recent outstanding reports illustrate the social, cultural and economic values of the region. (Smyth 2007; Scherrer et al 2008)

The decisions facing governments and all of the stakeholders overlap jurisdictional and discipline boundaries and require cooperation, co-investment and integrating action by the public, private and non-government sectors to bring on urgently-needed research that can be applied to achieve outcomes in the short-term. The research should also build a base so that ongoing results can be applied to future decision-making and management of the region.

An understanding of the ecology and biophysical make-up of the Kimberley-Browse marine region is critical for its future, the management and regulatory roles of government, the investments of stakeholders and the life of the Indigenous people. This report has discerned priorities that will require new research and new funding as well as some re-alignment of research work in Commonwealth and State agencies. Given the benefits available to the private sector, co-investment with the public sector in system-wide projects is also essential.

Co-investment in Research

Present research demonstrates the capacity for successful co-investment between the public and private sectors. This has a focus on areas of immediate interest to major stakeholders and is being undertaken to allow proposed developments to be assessed in accordance with legislative requirements. This report recommends that the scope of co-investment be expanded to include system-wide projects that will put the localised research into a regional context.

Examples of contemporary research include the Australian Institute of Marine Science (AIMS) study of the Scott Reef and surrounding areas supported by the Browse Basin Joint Venture Partners, the WA Museum's work on coastal habitats, research for the pearl fishing industry and INPEX's recent work around the Maret Islands. AIMS, Geoscience Australia and the CSIRO have ongoing research programs in the region or do work that is relevant to it. The Commonwealth and State governments are undertaking a joint assessment of locations for a multi-user hub to be the coastal focal point for the processing of liquefied natural gas. They have also initiated a joint strategic assessment of the values of terrestrial and marine areas of the Kimberley region for national (and possibly world) heritage listing.

The region is remote and research is more costly, possibly by two to three times more than in other northern tropical locations. The region has the potential to be listed as having World Heritage status. This status does not exclude developments in the region that are approved under the EPBC Act. Indigenous groups and leaders, governments and the private sector are aware of the importance of all the factors faced as decisions are made that will affect the environmental, cultural, social and economic values of the region. Some of these are imminent and pressing and will challenge decision-makers.

Several government and private sector programs are underway in the region and other Commonwealth and State programs for research and management are emerging. Further details are provided in the report. Taken together, these point strongly to the need for integrative science, undertaken at a strategic level and hosted and well-coordinated by WAMSI, to deliver high-quality results urgently and through work phased in over a period of years.

Estimates of the funding to support this proposed marine science program include $9m to address imminent government decision needs to mid-2010, and $20m per annum for five years with funding requirements reviewed prior to subsequent allocations being made in mid-2015.

The financial calculations have been made with reference to work in hand, to work announced in recent Commonwealth and State budgets and imputed

from marine science research completed at other tropical locations in Australia. These funds will provide sufficient resources to facilitate broad scale ecosystem science for the region and, nested within that context, detailed finer scale work on key priority areas of high conservation value and any areas designated for development.

Some public and private sources are already funding research in the region, as was noted above. Following the successes of integrating marine science projects conducted recently across jurisdictions and across disciplines it is recommended that many of the proposed projects must be funded through co-investment programs given the clear public and private benefits available as a result of the research. The information generated will be made available in the public domain to ensure transparency.

The scope of the science needed to understand and manage the ecology of the region goes well beyond what can be achieved by one-off projects, helpful as they can be to understanding portions of the region. The work of discovery and delivery takes time, an element that can be in short supply when some stakeholders face challenges of developing resources, securing finance and getting products to market while others expect governments to meet the needs of potentially competing uses. Better and more coordinated science is needed to support better decisions, now and into the future.

In order to achieve this balance, the report identifies shorter term and longer term priorities. The immediate shorter term (one to two year) science priorities will provide the marine science information required to support implementation of recent government initiatives for the:

- strategic assessment for a common user LNG processing hub site for Browse Basin gas and for ongoing management of the environment around the hub site, once selected;
- strategic assessment for National/ World Heritage Listing of the region; and
- Commonwealth Government North West Marine Bioregional Plan.

Longer-term (two to 10 year) priorities will demonstrate progress towards the vision for 2018 so that:

> *Planning, conservation, sustainable management and utilisation of the Kimberley's unique marine endowment are underpinned by an adequate understanding of the region's natural, cultural and socioeconomic values and systems.*

Urgent and immediate investment in research is needed to understand the ocean environment, its considerable and under-explored biodiversity and to gain a regional knowledge context of ecosystem processes and how they interface with cyclones, climate change, catchment and coastal land-sea processes. These science outcomes and system understandings underpin the regulatory management and policy decision roles of governments, industries, conservationists, Indigenous traditional landowners and the community. This will result in more informed and better decisions about the future. This work also supports the interpretation of detailed finer scale work supporting particular needs of coastal development, including infrastructure, industry requirements, conservation, natural resource managers, assessments of various types and numerous other policy needs. These are illustrated on pages 17 and 18.

Stakeholders at the March 2008 Kimberley-Browse Marine Science Policy Summit concluded that there is a clear need for strategic science to develop a systematic understanding of the region to address the challenges of sustainability and climate change, while at the same time delivering timely inputs into ongoing decision-making. The participants believed that WAMSI was a very good vehicle to facilitate the development of a Marine Science Plan for the region and to commence its implementation as a fully funded activity.

Marine Science Requirements

The Marine Science Case report (Appendix 2) identifies strategic regional priorities which cover multiple-use marine regional planning, maintenance of marine biodiversity and ecosystem integrity, protection of natural heritage and cultural values, improved community livelihoods, coastal/marine recreation, sustainable marine-based industries, planned coastal infrastructure, and managing the marine effects of land-uses and activities in the catchments. Understanding and adapting to the effects of climate change on the region is a priority that intersects with all the priorities listed above.

Four major Strategic Science Themes are proposed which address the regional priorities over a 10 year period. These are discussed in greater detail in the Marine Science Case report (Appendix 2).

They focus on documenting the region's values and assets, understanding its sustaining processes, identifying and responding early to potential threatening processes, and evaluating regional scenarios and management strategies for policy makers, communities and other stakeholders. The establishment of a Marine Monitoring Network and Performance Assessment System is also proposed to provide ongoing information to managers and users on the highly dynamic and variable marine conditions of this region which profoundly influence its marine ecology as well as its offshore uses and coastal communities.

In all, four phases of investigation and delivery are proposed to respond to immediate needs and to establish the science foundations for longer-term decision-making. The first phase will begin immediately and end in mid-2010. As a priority it will deliver marine survey information (including baseline habitat mapping, biodiversity assessments and oceanographic observations) in areas targeted for government decisions and at suitable reference locations. This work will also provide a basis for planning further work to be conducted during the subsequent phases.

The second phase will build on the first and end in 2015. It will address the strategic marine science requirements for decisions and ecologically sustainable development (ESD) of the region, by developing a representative understanding of the region's marine dynamics, its ecosystems, and human uses. This information is required for marine regional planning, management of marine biodiversity and ecosystem integrity, Indigenous values, sectoral ESD assessments, coastal infrastructure, environmental monitoring and management response to climate change.

The third phase will run to mid-2018, continuing to build on the strategic regional priorities. It will provide understanding of critical cause-effect pathways between climate change, human uses and marine ecosystems to improve monitoring and prediction of change, develop models of socioeconomic response to that change, and generate future scenarios to feed into planning processes.

The fourth phases should overlap with phase three and be ongoing. It will focus on implementation, evaluation, review and adaptation. This includes performance assessment against regional sustainability objectives; improved meteorological, ocean and long-term climate forecasts; reassessment and further projection of future scenarios for regional planning and further evaluation of management strategies in response to projected climate change and human use pressures.

In each phase, there will be a focus on the provision and use of scientific knowledge for decision-making at local, sub regional or regional scale. Table 3 at page 20 shows the timing of the phases and their links to information for decisions.

Recommendations

The report recommends that new funding be allocated to priority projects that characterise the values and assets of the region and, in the longer term, establish a predictive understanding of the region's key ecosystem processes and their responses to human and climate-induced pressures. Co-investment is also recommended.

These recommendations should be circulated to all stakeholders so they will be aware of the priorities in the report and consider them for inclusion in their own existing, emerging and proposed programs.

The recommendations are elaborated in the pages of the report immediately following this section. In summary, they propose that WAMSI's contributions are made across the range of strategic regional priorities. Many of these priorities reflect the interests of other stakeholders such as the Commonwealth government and marine-based industries as well as those of the Traditional Owners and the Kimberley Land Council. It is essential for the rapid development of knowledge that stakeholders contribute resources to the project.

recommendations

That WAMSI endorses this report and recommends to governments, industry and other stakeholders that as a matter of the highest priority:

1. new funding be allocated to establish critical baseline understanding of the natural and socioeconomic assets in the region, for decisions in the short (one to two year) term about:
    a. management of the marine region around the LNG Hub site;
    b. National /World Heritage Listing (State coastal waters);
    c. marine bioregional planning (Commonwealth waters); and
    d. environmental assessment of development proposals.
2. new funding be allocated to establish understanding of the region's marine ecosystems and predictions of their responses to human and climate-induced pressures, for decisions in the longer term (two to ten years) about:
    a. marine planning;
    b. conservation and sustainable natural resource management;
    c. environmental assessment of development proposals;
    d. land-sea interactions (e.g. coastal vulnerability and catchment-marine linkages); and
    e. management of climate change impacts.
3. other stakeholders and private sources support achievement of the priorities.
4. co-investment in priority projects that are regionally important to stakeholders generally be undertaken.
5. a budget proposal be prepared for 2009-2010 recommending the allocation of State government funds which, when combined with co-investment from the Commonwealth government, industry and other stakeholders, will total $20m each year for five years. The share contributed by the State government is recommended to be one third of the funds sought.
6. the budget submission includes expressions of support for co-investment from Commonwealth agencies, universities and the private sector.
7. stakeholders in the region agree to provide access to marine data and information for strategic research relevant to the broad objectives of the proposed marine science program.

Recommendations to WAMSI Arising from the Marine Science Case

Subject to this Business Case being resourced, the Marine Science Case report (Appendix 2) recommends implementation of a number of actions in relation to the proposed WAMSI-coordinated science program in the Kimberley-Browse marine region.

Strategic Recommendations

1. That WAMSI coordinate a program of strategic marine science in the region to address knowledge requirements for the following regional priorities:
    - marine regional planning;
    - maintenance of marine ecosystem integrity, biodiversity, cultural and heritage values;
    - sustainable management of multiple uses;
    - productive marine industries and innovative marine technologies;
    - land-sea interactions (coastal vulnerability and catchment-marine linkages); and

- prediction of regional climate change impacts on marine ecosystems and human uses, risk assessments and development of adaptive management strategies.

2. That the WAMSI marine science program addresses knowledge requirements for decision processes affecting the Kimberley-Browse marine region, including:
   - joint Commonwealth/State strategic assessment of a common-user LNG Hub, once preferred locations have been nominated by government;
   - subsequent decisions relating to a Hub such as its marine infrastructure layout, management of the surrounding marine area and assessments of subsequent proposals for industry collocation within the hub.;
   - joint Commonwealth/State government strategic assessment of the Kimberley marine heritage values against criteria for National (and World) Heritage Listing;
   - subsequent decisions related to a Heritage Listed area such as a management plan with strategies for conservation, sustainable use and Indigenous participation, and performance measures and indicators for monitoring to audit achievement of management objectives;
   - integration of Indigenous knowledge to enhance understanding and management of marine and coastal environments.
   - Commonwealth Marine Bioregional Planning (NW Bioregion). Subsequent decisions, also requiring science inputs, would include preparation and implementation of a management plan;
   - environmental assessment of development proposals and environmental management of developments (e.g. offshore gas developments, port expansion, changes in catchment land use);
   - the establishment and management of a system of marine protected areas; and
   - sectoral management plans for fisheries, pearling, aquaculture, marine-based tourism, and industry, based on ecologically sustainable development (ESD) principles.

General Recommendations

3. That WAMSI, as a matter of priority:
   - identifies and make appropriate arrangements with organisations which may become new WAMSI research partners, direct research collaborators (working in the region), indirect research collaborators (working on similar problems in other tropical marine regions), or data providers (e.g. river flow data).;
   - consults with, inform and seek permission from Traditional Owners to conduct research and provide opportunities for Indigenous participation, employment and training;
   - identifies and make appropriate arrangements with other public or private organisations from which specific permission or approvals are required to undertake the proposed research work;
   - seeks agreement from industry proponents, operators and other private organisations for access to metadata holdings and to marine data of relevance to WAMSI strategic marine research; and
   - continues to strengthen resourcing of marine data and information management systems, with an emphasis on open access, knowledge transfer and integrating data streams in near real-time.

Science Recommendations

Specific research recommendations are listed below for each of the major Themes included in the proposed science program for the Kimberley-Browse marine region. Implementation of these recommendations should incorporate and build on available, existing data and information.

Values and Assets

4. That WAMSI, through coordination with its research member parties:

    - establish a live database of historical and current human use patterns and pressures in the region, and assess future trends;
    - integrate Indigenous knowledge of the values and assets of the region, through consultation with Traditional Owners and their representatives, and collaboration with relevant researchers;
    - apply cost-effective methods to develop broad scale maps of seabed geomorphology, marine sediments and underlying geology for use as surrogates of habitat and biodiversity distribution. These should be coordinated with targeted surveys of biological communities at selected sites to develop and verify habitat/community auto-classification schemes for use in interpretative mapping;
    - conduct targeted surveys to characterise the marine benthic communities across the region, particularly the marine environments in state coastal waters. These surveys should define the environmental requirements, the dominant species assemblages and distribution of key communities across a representative range of environmental settings. The surveys should include biological sampling for taxonomic analysis;
    - conduct targeted surveys to define and map the regional extent, diversity and variation of fringing coral reef communities in the Kimberley. This would enable these Holocene fringing reefs to be compared with other coral reef systems in Western Australia, Australia and internationally;
    - develop classifications for habitat mapping, habitat condition and habitat loss;
    - identify critical habitat of threatened marine fauna including dugong, marine turtle and humpback whale. This should include breeding and feeding areas and the critical seasonal periods for these activities;
    - assess the population size and distribution and the Indigenous harvest of dugong and marine turtle to understand and manage the populations of these marine fauna;
    - design programs for monitoring baseline variability and long-term trends in key water column, sediment and biological structure and condition indicators at carefully selected sites and locations, including 'unimpacted' reference areas and nodes of human activity. Sustained, systematic monitoring is required to detect long-term trends associated with climate variability, climate change, and possible anthropogenic influences;
    - establish baseline data and long-term monitoring to understand the land-sea interaction and the quality of terrestrial runoff entering marine waters off the Kimberley coast;
    - initiate research on interpretation of remote sensing data to improve estimates of marine properties such as surface temperature, suspended sediment and chlorophyll concentrations (the latter used as an index of phytoplankton biomass) across inshore and shelf waters of the Kimberley-Browse region. Ground truthing and calibration of remotely-sensed ocean colour data in coastal waters is a priority area; and
    - incorporate baseline and periodic monitoring of the biosecurity status of the region, and documentation of any new species introductions.

Sustaining Processes

5. That WAMSI, through coordination with its research member parties:

    - gives early attention to developing an understanding of the region's response to broad scale ocean-climate forcings. Within that regional context, investigate and model the role of fine scale processes – physical,

biogeochemical and ecological - for selected locations of agreed high priority;

- initiates an integrated field measurement, data analysis and numerical modelling program to characterise the physical processes which govern climate (including extreme events such as cyclones), marine hydrology, water circulation, marine connectivity among habitats, tidal dynamics, waves and sediment mobility in the region;
- initiates an integrated field measurement, data analysis and numerical modelling program to investigate the key biogeochemical and ecological processes which, together with the physical processes, govern patterns of biological productivity, biodiversity and resilience of the region's ecosystems. This should be closely linked to the physical processes program;
- develops an accurate shelf-scale nutrient budget for the Kimberley region;
- selects several locations of agreed high priority (e.g. proposed development areas, high conservation value areas and other reference locations) for integrated, high resolution modeling and research (e.g. physical energetics, water column variability, benthic habitat and community dynamics, food web interactions and other ecological linkages); and
- initiates research to develop interpretation of remote sensing data for marine properties such as circulation, sea level, surface temperature, turbidity and chlorophyll, with particular emphasis on shelf and inshore waters of the Kimberley-Browse region.

Threatening Processes

6. That WAMSI, through coordination with its research member parties:
   - conducts risk assessments to identify threatening processes and critical cause-effect pathways for priority research;
   - identifies environmental requirements of key species and communities;
   - investigates critical cause-effect pathways to identify practical, early warning indicators of environmental change and sub lethal response indicators in the key species and/or biological communities found in the region;
   - investigates the linkages between coastal water quality and the health and resilience of near shore coral reef ecosystems;
   - develops effective bio-indicators for measuring and monitoring sub-lethal stress in tropical marine organisms arising from poor water quality; and
   - investigates responses in marine ecosystem composition, structure and function to physical and chemical manifestations of climate change.

Scenario Assessment and Management Strategy Evaluation

7. That WAMSI, through coordination with its research member parties:
   - assembles research relevant to the region on ecosystems (or key ecosystem processes), human uses, climate change, adaptive management strategies and monitoring approaches;
   - determines the scope, application and development of regional scenario assessments and management strategy evaluation in early consultation with managers, stakeholders, researchers and communities;
   - identifies information requirements and address these through the broader WAMSI program;
   - in consultation with managers, stakeholders, researchers and communities, maps broad objectives into specific and quantifiable performance indicators to provide a basis for assessment of future scenarios and evaluation of alternative management strategies; and

- analyses prospective social and ecological impacts of multiple-use management strategies in a risk-assessment framework, giving attention to conservation, Indigenous, fisheries, aquaculture, tourism, coastal development and mineral extraction issues, in the context of regional climate change.

Marine Monitoring Network and Performance Assessment System

8. That WAMSI, through coordination with its research member parties:

    - seeks collaboration with Australia's Integrated Marine Observing System (IMOS) and with potential contributors from Commonwealth, State and local agencies, industry, and universities to develop an integrated, flexible, cost-effective marine and coastal monitoring network and performance assessment system for ongoing use by resource managers, operators, ocean forecasters and researchers;
    - contributes to the design and implementation of the system, in consultation with IMOS, resource managers, operators and researchers;
    - promotes the use of cost-effective, new technologies able to capture marine data over broad areas and long time spans (e.g. satellite remote sensing, robotic in situ platforms, wireless sensor networks and novel sensors), and the 'assimilation' of data into ocean simulation models to provide marine forecasting and analysis products;
    - uses data from the network to investigate responses of the region to broader ocean-climate behaviour, and to improve understanding of climate change within the region; and
    - develops a performance assessment system based on monitoring of ecosystem variability and health at selected reference locations throughout the region, and areas under stress, and facilitates linkages with localised monitoring programs (e.g. compliance monitoring).

"An understanding of the ecology and biophysical make-up of the region is critical for its future, the management and regulatory roles of government, the investments of stakeholders and the life of the Indigenous people."

the Kimberley-Browse marine region

This section of the report describes the region, its values, resources, people and stakeholders prior to discussing the opportunities and needs now surfacing in the context of rapid change. It then examines the major regional issues and human uses, noting that there are significant and targeted information needs to support the achievement of government objectives and the goals of stakeholders. The section concludes with a brief assessment of why the marine science knowledge of the region must catch up with the requirements of government and stakeholders for better science to support better decisions.

Regional Setting

The Kimberley-Browse marine region is located off the northern part of Western Australia and extends (see map on inside front cover)

- alongshore, from the southern end of the Eighty Mile Beach, south of Broome, to the Western Australia/Northern Territory border; and
- offshore, from the high water mark to the edge of Australia's extended continental shelf jurisdiction, including all of the Maritime Zones declared under the Commonwealth *Seas and Submerged Lands Act* 1973. These zones comprise: Western Australian State Coastal Waters, the Territorial Sea, the Contiguous Zone, the Exclusive Economic Zone and the Australian Fishing Zone.

The region is influenced by the south east Indian Ocean circulation and the Indonesian Throughflow, the world's only low latitude conveyor of water and heat between oceans. This area is considered to be very important for understanding the global climate system and is known to influence rainfall across southern and western Australia as well as the variability of the Leeuwin Current.

A wet and a dry season characterise the region's tropical monsoon climate. During the wet summer season sporadic tropical cyclones and severe tropical storms occur with strong localised winds and heavy rainfall. The region is macrotidal, with large spring tidal ranges (up to 11.7 m in coastal waters) and strong tidal currents.

Seven marine mesoscale bioregions have been identified in this highly diverse area (Commonwealth of Australia, 2006). Five of these bioregions are coastal marine (Eighty Mile Beach, Canning, King Sound, Kimberley, Bonaparte, Cambridge-Bonaparte) and two are offshore (North West Shelf, Oceanic Shoals).

The Kimberley-Browse marine region contains a remarkable array of complex and unique habitats which support high levels of biological diversity. The Kimberley has fringing coral reefs that are more extensive and diverse than Ningaloo and the region may well become known as a coral reef province of global significance. In addition to the diversity of corals, fish, molluscs and other invertebrates, the region hosts a wide variety of larger marine animals such as sea turtles, crocodiles, manta rays, whales, dugong and dolphins, and is thought to have retained a high degree of ecological integrity compared with other large tropical marine ecosystems of the world.

The unspoilt scenic beauty and recreational experience offered by its coastal waters, islands and outer shelf atolls is attracting an ever-increasing number of visitors and tourists to the Kimberley.

Extending to the north west boundary of Australia's territorial jurisdiction, the Kimberley-Browse marine region has marine connections with the biologically diverse, but heavily exploited seas of south east Asia. The region is of strategic importance for defence preparedness, customs surveillance, border control and security for its offshore resource developments. Each of these strategic functions along with other maritime operations such as shipping, commercial fishing, marine-based tourism, sea search-and-rescue

(and other emergency operations) will benefit from improved understanding of the region and enhanced forecasting of its weather and ocean state behaviour.

People and Resources

The region has a low population base with relatively few towns and settlements, but it is growing rapidly. Aboriginal people comprise almost half of the current population. The Indigenous cultural values are unique assets of the region.

The recent excellent bibliographic study *Sea Countries of the North-West* (Smyth 2007) highlights the significant Indigenous knowledge of the region. It also contains important recommendations for the involvement of Indigenous people in fishing, fishing management and economic development of the sea countries.

The Kimberley-Browse marine region currently supports a range of industries including marine-based tourism, commercial fishing, aquaculture (mainly pearling) and mining. The region's ports ship cattle and mineral products, support large cruise ships, charter, pearling and offshore supply vessels, and import commodities.

Very large reserves of natural gas and petroleum have been discovered at offshore locations in the Browse and Bonaparte basins and other offshore fields. Known gas reserves in the Browse Basin alone exceed 31 trillion cubic feet (Government of Western Australia, 2006).

There are other land-based activities including oil, gas, cattle-production, agriculture and horticulture, and diamond and other mineral extraction that can have impacts on the coastal zone.

On the Threshold of Change

The region is on the threshold of change. Movements in climatic and marine processes have the potential to impact on existing uses of the sea and the coast; human access to the region is growing on both land and sea and leading international and Australian companies are seeking approvals for the exploitation of oil and gas reserves. High levels of exploration suggest future extraction of oil and gas is likely to continue for decades to come. The Kimberley Land Council (KLC) has emerged as a body representing the interests of Indigenous people in the region. Announcements by other representative, public policy research and advocacy groups in and outside the region are testament to the importance of its environment at international, national and local levels (e.g. PEW 2008).

The Commonwealth and Western Australian governments have recognised the status of the region and have announced decisions on marine bioregional planning and strategic assessments to protect and manage important Indigenous heritage, environment and tourism values, while facilitating structured industrial development. (Joint Ministerial Statement 2008, Department of Industry and Resources 2008).

The KLC has announced that it seeks long-term benefits for Indigenous people from the proposed developments and the State government has confirmed that the "informed consent" of Indigenous people will be a condition of developments proceeding.

Opportunities and Needs

There are opportunities for governments and stakeholders to make exceptional decisions together that will leave an outstanding and unparalleled legacy for existing and future generations; for existing and potential users to contribute to an enduring knowledge of the environmental and social values of the region while seeking economic benefits from it; for Indigenous people, government agencies and stakeholders to build a shared and growing body of knowledge about the region and its sustainable management into the future.

However, resources are required to realise these opportunities. Ecosystems which sustain marine life are not restricted to boundaries established by laws and international protocols. Coral reefs are affected by events and pressures originating elsewhere in the region and beyond; the impact of a LNG hub

might be felt outside its prescribed location; water quality and inshore habitats may be affected by land use practices in the catchments. Stakeholders should be prepared to commit resources over time to a comprehensive understanding of the ecology of the region, recognising that what happens in their immediate location might be affected by and itself affect other aspects of marine life in the region. Both public and private benefits will result from such research expenditure.

In circumstances where comparatively little research has been done, an outline of needs begs for a list of priorities. Government objectives and decisions already point to the immediate needs and these are covered elsewhere. A summary of longer-term priorities is outlined in Table 3 (page 20).

Issues

Managing inter-related issues that cross jurisdictional and discipline boundaries is tough work, particularly when the quantum of relevant data is comparatively scarce, its collection lacks alignment with announced priorities and there is urgency about the need for decisions. In these circumstances, leaders make the best decisions they can with the available information. In the case of the Kimberley-Browse marine region, there are several important issues needing attention including the environmental assessment for a LNG hub, once the site has been selected.

Management Arrangements

Management responsibilities have been established under different Commonwealth, State or local government legislation for various matters including: conservation of natural and cultural heritage values; conservation of flora and fauna; maintenance of biodiversity; marine protected areas and marine conservation reserves; fisheries and fish habitat management; land use planning; ports; industrial and resource development, and tourism. These management arrangements are administered by different agencies from the various levels of government.

The absence of an overarching marine plan to coordinate these management functions and the limited resources that each agency is able to deploy in the region, presents an impediment to progress toward regional sustainability. This lack of management coordination probably explains the relatively low level of past investments in understanding marine processes and documenting fundamental baseline information at an ecosystem or regional scale.

National/World Heritage Listing

The Commonwealth and Western Australian governments have initiated a joint strategic assessment of the values of terrestrial and marine areas of the Kimberley for national (and possibly world) heritage listing (Joint Ministerial Statement 2008). Following a heritage listing, it is likely that work would commence toward a multiple-use marine managed area, with a management plan and science fully integrated into decision-making processes.

Conservation of Biodiversity

Marine biodiversity confers many benefits such as ecosystem function and resilience, storage and recycling of nutrients, maintenance of nursery habitats for migratory fauna, maintenance of fish stocks, shoreline/coastal protection and visual amenity (CRC Reef 2003).

It is biodiversity that underpins marine-based industries and human uses such as fishing, tourism, bioprospecting (for useful compounds found in marine organisms), Indigenous use, education, research and aesthetic enjoyment.

A knowledge of where areas of high biodiversity occur is essential for marine planning to ensure that these areas are well protected and managed, and to provide confidence that areas designated for specific human uses are appropriately located and managed. Considerable work is required to achieve an adequate understanding of biodiversity distribution.

Marine biodiversity may be threatened by direct physical disturbance (e.g. benthic trawling), pollution, sediment and nutrients discharged from river catchments, overfishing, marine pest infestations, ocean warming and acidification, and increased sea level. Systems already under stress from one threat tend to become more susceptible

to stresses from other threats. A well-designed monitoring program, capable of discriminating between natural variability, anthropogenic and climate-induced changes is required to inform management in the region.

Sustainable Uses

Marine-based tourism, fishing, pearling and aquaculture are three existing uses where stakeholders have expressed concern about sustainability in the context of change.

There has been dramatic growth in coastal and marine-based tourism in the Kimberley over the past 10-15 years. Commercial tourism businesses include fishing boat charters, whale watching expeditions, remote wilderness coastal camps, extended Kimberley cruises, scenic coastal flights and offshore diving expeditions. The longer range cruises extend right around the Kimberley coast and the diving expeditions range 300 km offshore to the Rowley Shoals.

A substantial and very important technical report prepared for the CRC for Sustainable Tourism on tourism and the Kimberley coastal waterways concludes that there is an "urgent need for an improved governance framework and the development of appropriate statutory and non-statutory mechanisms to facilitate accountability in coastal planning and development of the Kimberley coastal area." (Scherrer et al 2008)

This comprehensive report contains information on current tourism operations, the biological and physical impacts of expedition cruising, the views of stakeholders including traditional owners and the management issues raised by them and other stakeholders. It makes recommendations for legislative review and provides protocols for engaging with Indigenous Western Australians.

Aquaculture along the Kimberley coast is dominated by the production of pearls from the species *Pinctada maxima*. Other aquaculture activities are focused on production of barramundi, redclaw and trochus (for reef enhancement), and on developing the black tiger prawn industry and Indigenous aquaculture (Fletcher & Head 2006). The Department of Fisheries advises that, along the Kimberley coast in 2008, there were 89 pearl farm leases, status 'leased', occupying approximately 58,271 hectares and 40 aquaculture sites, status 'licensed', occupying approximately 30,243 hectares.

The Kimberley's pearling industry, with an estimated annual worth of up to $130 million, has three main components: the collection of pearl oysters from the wild, production of hatchery-reared pearl oysters and grow-out of pearls on pearl farm leases.

Jernakoff & Wells (2006) report an analysis of the main potential environmental and ecological risks that arise from the various activities carried out by the *P. maxima* industry. Of the 23 risks identified, none were assessed as high and only three as moderate risks, namely: introduction of disease from seeding; attraction of other fauna and introduction of exotic organisms. All of these risks were considered to be manageable.

The Kimberley also looks likely to experience significant growth in seacage fish aquaculture (e.g. barramundi). Unlike the pearl industry, fish culture requires artificial feeding. Artificial feeding introduces nutrients and particulates to the area which, together with fish faeces, may have the potential to modify the seabed and benthic communities. Waste feed material may attract marine fauna to the area and this may increase the risks of disease transfer and of marine mammal entanglements. Escape of cultured fish from the seacages may impact on the genetics of wild, endemic fish populations.

It is clear then that site selection, risk assessment and management for sustainable aquaculture operations requires knowledge of the hydrodynamics, seabed substrates, habitats and marine communities, within and surrounding the lease site.

There are 13 managed wildstock fisheries in the region. The principal fisheries focus on finfish, particularly the high-value emperors, snappers and cods. There are a number of limited-entry trawl fisheries for prawns. There are also significant fisheries for Spanish mackerel, barramundi, threadfin salmon and shark.

Recreational fishing is experiencing significant growth, particularly in winter when there is an influx of tourists to the region. Recreational fishing occurs independently or by commercial charter. Locations regularly visited by charter vessels for fishing include the 10 major river mouths along the Kimberley coast and distant offshore reefs at Scott, Seringapatam, Ashmore and Cartier.

The Kimberley-Browse marine region is increasingly coming under threat from international poaching (particularly for sharks) and illegal fishing in offshore regions. Potential impacts of climate change on the fisheries are unknown. Other risks for the fisheries of the region include the potential for transfer of diseases, introduction of exotic pest species, inshore impacts from coastal developments, changes in catchment discharge, and competition for access to inshore marine areas.

Overfishing and unwanted by catch diminishes fish stocks and may have serious ecosystem consequences. Significant impacts to benthic communities (e.g. sponge gardens) occurred in some areas subjected to past trawling. These communities have very long recovery times. New technologies are now available to better characterise the seabed biodiversity and assist regulators so that trawling is not allowed in areas where unacceptable impacts would occur.

Individual fishery status reports are now prepared annually using an ecologically sustainable development (ESD) reporting approach. Integrated fisheries management (IFM) is a framework designed to address the growing competition for fish resources between commercial, recreational and Indigenous fishers (Government of Western Australia, 2008).

Climate Change

At the 2006 International Tropical Marine Ecosystems Management Symposium (International Coral Reef Action Network, 2006), 324 of the world's leading tropical ecosystem scientists and managers, from 45 countries, stated that...

> *'Climate change is now recognised as one of the most serious long-term threats to the biodiversity and services provided by tropical marine ecosystems.'*

Significantly, they went on to state that...

> *'Managers can take action to reduce the impacts of climate change in tropical marine ecosystems.'*

The action of managers will benefit from data and analyses that assist an understanding of climate change in the context of the Kimberley. While this understanding is increasing as government agencies embark on research, more needs to be done.

The Indian Ocean Climate Initiative (IOCI) Stage 3 project focuses on the current and projected terrestrial climates of the north west and south west regions of WA, while WAMSI projects focus on oceanic drivers, marine responses and coastal vulnerability to climate change. Complementary outcomes from IOCI Stage 3 and WAMSI projects will provide a more complete understanding of the Western Australian climate and will better inform the development of adaptive management strategies.

Energy

The region has large reserves of petroleum and gas at offshore locations in the Browse and Bonaparte Basins and in other offshore fields. The Browse Basin alone already has 31 trillion cubic feet of known gas reserves. The operating lifetime of the known fields is likely to be well over 40 years, with a high probability of further significant finds in the region (Government of Western Australia, 2006).

Woodside Energy Ltd and its Browse Joint Venture partners, BHP Billiton, BP, Chevron and Shell are proposing to develop the Torosa, Brecknock and Calliance gas fields located approximately 290 km off the Kimberley coast in the Browse Basin (Woodside Energy 2008). INPEX is proposing to develop the Ichthys Field (also located in the Browse Basin) to produce condensate, liquefied petroleum gas (LPG) and liquefied natural gas (LNG) for export (INPEX Browse Ltd 2007). Shell has submitted to the Commonwealth government a proposal for a 3.5 million tonne per year offshore floating LNG plant to process and export LNG from the Prelude gas field which lies 450 km north east of Broome in the Browse Basin.

In February 2008 the State and Commonwealth governments announced a joint strategic assessment process to identify a preferred site for a common-user LNG hub precinct for the Browse Basin (Joint Ministerial Statement 2008). It is envisaged that the LNG hub would have the capacity to process and export gas from several major offshore developments and to provide a natural gas feed for collocated industries. This assessment process is scheduled for completion in mid-2009.

The identification of a hub location will be followed by a wider strategic assessment of the natural and cultural values of the region, in consultation with conservation groups, industry and Indigenous landholders. (Joint Ministerial Statement 2008).

Design, installation and operation of offshore petroleum and gas production and pipeline facilities requires a detailed and predictive knowledge of meteorological and oceanographic conditions, including extreme events such as cyclonic winds and waves, together with an understanding of the geotechnical properties and stability of the sea floor.

Environmental issues associated with offshore operations may include physical and seismic disturbances, drill cutting releases, produced formation water discharges, unscheduled failures or spill events. These disturbances can potentially have adverse direct or indirect impacts on pelagic and benthic communities. For onshore LNG processing and export facilities, the environmental issues include construction and workforce impacts, dredging operations, the infrastructure footprint (changes to coastal form and bathymetry), waste water discharges, unscheduled leaks and spills, noise, vibration, and light spill. These disturbances can impact on water and sediment quality, benthic habitats, marine biological communities and migratory marine fauna. They also have the potential to break-up the "wilderness" integrity and heritage values of the region.

These potential impacts indicate the need for collaborative and integrative science to be undertaken by stakeholders whose responsibilities and interests extend beyond boundaries established by protocols, laws or permits.

Mining

Mining of high grade iron ore on Cockatoo Island and Koolan Island in the Buccaneer Archipelago commenced 50 years ago. Ore extraction at Cockatoo Island resumed after the construction of a seawall in 2000, enabling sub sea level mining of the resource. Other iron ore deposits are currently being surveyed on Irvine Island.

Exploration for marine diamonds in the Joseph Bonaparte Gulf, to the north of Wyndham continues, and there are several deposits of mineral sands in King Bay and Pender Bay (CSIRO 2007). A large number of terrestrial mining tenements are active throughout the whole Kimberley.

Bulk nickel/copper/cobalt concentrate is transported by road to the Port of Wyndham for export. Lead and zinc concentrates are barged from the Port of Derby (Government of Western Australia 2006).

Export of minerals requires port infrastructure, stockpiling and ship loading. There is potential for release of particulates and toxicants into the marine environment arising from drainage and airborne dust emissions from stockpiles, as well as spills and dust during ship loading. Vessels manoeuvering in inner port areas resuspend natural and introduced particulates increasing turbidity. Shipping carries with it the risk of marine pest introductions which can have serious consequences, both for ecosystems and commercial uses. Submarine mining disturbs the sea floor and impacts on benthic habitats and communities. It resuspends sediments, increasing turbidity and reducing light available at the sea floor.

Land-sea interactions

The Kimberley region forms a large part of the Timor Sea drainage division which receives more than 20 per cent of Australia's total rainfall (National Land and Water Resources Audit 2001). Tropical cyclones and storms occur during the wet summer season, bringing strong localised winds and heavy rainfall. These events may generate storm surges at the coast with severe inundation in low lying coastal areas. They also account for the highly variable freshwater, sediment and nutrient loads being discharged from the mainland Kimberley rivers and streams into the marine environment.

Climate variability and land use practices, such as increased fire regimes and river regulation, have a direct bearing on the rates of water, sediment, nutrients and other materials discharged. Little is known, however, about the influence of these factors on the biodiversity, productivity, nursery habitats, and environmental quality of the nearshore marine environment in the Kimberley Region, but studies from other tropical regions in Australia demonstrate that changes in land-sea interactions can detrimentally affect water quality and marine ecosystems.

Coastal seas are complex mixing zones between the land and the ocean. On narrow continental shelves, much of the terrestrial materials exported by rivers can pass straight to sinks in the deep ocean. On broad continental shelves as occurs in the Kimberley these materials are likely to be trapped and recycled near the source. Additional nutrients can also be imported onto the outer shelf from oceanic sources by upwelling at the shelf break. Ultimately, the productivity of benthic and pelagic ecosystems on the continental shelf depends upon the biogeochemical cycling of nutrients from these two sources (land and ocean).

Because of projected constraints on the availability of water in southern Australia and the growing global importance of food commodities, there is increasing pressure to expand irrigated agriculture in northern Australia. The Northern Australia Irrigation Futures (NAIF) project aims to ensure that irrigation in northern Australia is planned and managed sustainably within a catchment context. The Northern Australia Land and Water Taskforce established by the Commonwealth government is to consider a broad range of development opportunities related to water use, including tourism, mining and other industry.

The Tropical Rivers and Coastal Knowledge (TRaCK) project seeks to understand and predict how material budgets (water, sediments, nutrients), aquatic food webs and biodiversity in the river systems would change in response to development and climate change.

Catchment managers need information on how their decisions affect the marine environment. The science is yet to be done to meet these needs.

addressing resource management needs

The WAMSI initiative will address the knowledge requirements of ecologically sustainable, integrated planning and management, conservation and resource utilisation in the Kimberley-Browse marine region. Knowledge transfer will be achieved through coordinated and applicable research relevant to all stakeholders.

Ecological sustainability incorporates environmental, social, and economic considerations. Sustainable management for the region involves all levels of government, the private sector and the community. Recent Commonwealth and State government initiatives provide the impetus for a regional sustainability framework within which sectoral and individual decisions can be taken.

The provision of underpinning science, both at a strategic and individual decision level, will provide greater confidence in the community that options have been thoroughly considered, future scenarios, risks and cumulative impacts assessed, and that decisions are well-founded. It will provide greater certainty for decision-makers, greater security for end-users, and benefits in terms of safer, more efficient and environmentally sensitive operations.

Within this context, the strategic objectives of the WAMSI proposal are to:

- generate knowledge required for natural resource management in the region;
- interpret and transfer this knowledge to decision-makers in a timely manner;
- build regional and State capacity in marine resource management, science and innovation; and
- promote understanding of marine resource management issues in the community.

Generating Knowledge

Sustainable management of the region demands knowledge of the interactions between its ecosystems, its human uses and the emerging influences of climate change. For most of the Kimberley-Browse marine region, these interactions are poorly understood. Generating the information requirements for current and future management decisions will require a sustained and coordinated program centred around four strategic science themes and supported by an enabling data acquisition and management theme, as outlined below. It will be essential to maintain currency in data sets and contemporary relevance of science-based management understanding, to keep abreast of increasing pressures, emerging challenges and new opportunities in the region.

Theme 1: Values and Assets

The Kimberley-Browse marine region has a truly unique set of values and assets, knowledge of which is fundamental to the sustainable management of the region. Its human use values (Indigenous cultural, social and economic) are intrinsically linked to its natural and ecological values.

Objectives

This theme will:

- identify and map the natural, ecological and human use values of the region;
- integrate Indigenous knowledge, values and understanding of the region; and
- determine baseline, natural variability and long-term change in marine ecosystem condition and report trends in human use intensity.

Benefits

Benefits arising from theme 1 will include:

- identification of areas with high biodiversity, cultural or heritage values that are worthy of special management status (e.g. National Heritage Listing, Marine Protected Areas);

- greater certainty in management of marine-based human uses and activities (e.g. fishing, pearling, tourism, cultural use, recreation);
- reduced risk in site selection and management of marine and coastal infrastructure;
- targeted environmental regulation to protect known values and assets; and
- more effective community involvement in natural resource management.

Theme 2: Sustaining Processes

Environments and ecosystems function as a result of interacting processes which operate across a wide range of time and space scales. Sustaining processes deliver the environmental flows of energy, materials and genetic information which maintain the biodiversity and productivity of marine ecosystems, and the many services they provide to mankind.

Objectives

This theme will:

- characterise the broadscale drivers of climate variability in the region and its connectivity with surrounding tropical and temperate marine regions;
- determine the major physical, biogeochemical and ecological processes that shape the region's ecosystems and condition its human uses; and
- develop integrated physical, biogeochemical and ecological models for the Kimberley-Browse marine region, to enhance understanding of marine system behaviour and ecosystem responses to human pressures and changed environmental conditions.

Benefits

Benefits arising from theme 2 will include:

- greater understanding of water, nutrient and sediment flows, extreme events, habitat dynamics, biodiversity, biological productivity, food webs and critical environmental requirements of marine flora and fauna;
- improved conservation, fisheries, pearling and tourism management and operations based on better understanding of essential natural processes;
- reduced risk for maritime structures, navigation and offshore operations, including the petroleum and gas industry, through improved knowledge and predictions of oceanographic and meteorological conditions; and
- improved regional climate change predictions (e.g. cyclone intensity, storm surge, rainfall, sea level, ocean temperature) and better adaptive management.

Theme 3: Threatening Processes

Threatening processes refer to the cause-effect pathways between pressures (because of natural or anthropogenic factors) and their consequential impacts on the ecological or human use values in the region.

Objectives:

This theme will:

- investigate key cause-effect pathways prioritised on the basis of risk assessments;
- identify performance measures (i.e. monitoring indicators) early in the human pressure-environmental receptor pathways and develop practical, standardised monitoring and reporting protocols; and
- quantify benchmarks against which measures of these indicators can be compared to gauge ecosystem health and resource condition trends.

Benefits

Benefits arising from theme 3 will include:

- ability to effectively monitor the region's high risk pressure-impact pathways;

- consistency in monitoring indicators, methods and reporting protocols used across the region, resulting in better coordination between surveillance and compliance monitoring programs;
- improved information for marine conservation management, industry environmental performance review, catchment management and sustainability assessments for fisheries, tourism and other industry sectors; and
- better understanding of the effects of climate change on the region's marine and coastal ecosystems, and better adaptive management.

Theme 4: Scenario Assessments and Management Strategy Evaluation

This theme draws on knowledge, understanding and information from various research disciplines (both the natural and social sciences), sectors of society (both Indigenous and non-Indigenous), end-users and government policy agencies.

Objectives

This theme will:

- bring together research on ecosystems (or key ecosystem processes), human use interactions, climate change, adaptive management strategies and monitoring approaches;
- develop regional scenarios of climate variability, human use activities, ecosystem change (including changes in ecosystem services), social responses and adaptive management strategies; and
- generate and compare alternative management strategies and future scenarios against ecological and socioeconomic targets.

Benefits

Benefits arising from theme 4 will be to:

- assist planners, managers, end-users and the community to explore and assess the relative risks and implications of alternative strategies and scenarios prior to making decisions.

Theme 5: Marine Monitoring Network and Performance Assessment System

This theme centres on the establishment of an operational data acquisition and information management system that enhances all of the strategic science themes and provides ongoing services to managers and operators in the region.

In many marine regions there is little or no coordination between individual monitoring and research programs, and this lack of integration is an ongoing, serious impediment for managers and operators.

With the largest tides and the largest incidence of tropical cyclones anywhere in Australia, the Kimberley-Browse marine system is extremely dynamic, and this, in combination with a warming Indian Ocean, profoundly influences the region's marine ecology and productivity, as well as its offshore uses and coastal communities. Any attempt to manage its marine resources and human uses, therefore, must be accompanied by detailed information on the region's ocean dynamics.

Implementation of a sustained Kimberley-Browse marine monitoring network coupled to a marine data and information management system is required to deal with these issues. The network would gather information on the effects of weather, climate and anthropogenic pressures on marine ecosystems, living resources and human commercial and recreational activity in the region. It would feature cost-effective, modern technologies able to monitor broad marine areas and/or long time spans (e.g. satellite remote sensing, robotic in situ platforms, wireless sensor networks and novel sensors) and make the information available in near real time via a central database. These data streams would be 'assimilated' into ocean simulation models to provide detailed marine forecasting and analysis products for managers and operators, analogous to present day meteorological observation and forecasting systems. They would provide vital information to researchers and managers about the responses of the Kimberley-Browse marine region to broader ocean-climate behaviour and necessary data to understand climate change and its impacts within the region.

Implementation of such a network would best be accomplished through coordination between WAMSI and Australia's Integrated Marine Observing System (IMOS). There would be value in linking future IMOS investment into the Kimberley-Browse initiative. IMOS is funded by the National Collaborative Research Infrastructure Strategy. It is envisaged that a Kimberley-Browse marine region observing network could be developed and implemented as a partnership across Federal, State and local agencies, industry, and universities (essentially the WAMSI partners). In addition to their direct regional applications, these marine data could also be linked to other Australian and international data sets to provide a more comprehensive approach to marine and climate change research and predictions. Both the national IMOS framework and the Intergovernmental Oceanographic Commission (which has an office in Perth) may have a role to play in this respect.

The performance assessment system would facilitate management and coordination of environmental monitoring data from selected reference locations throughout the region, and areas under pressure. The system would manage data from both broader surveillance and localised monitoring programs (e.g. compliance monitoring). It would document the indicators, benchmarks and monitoring methods used and highlight unexpected results and any inconsistencies between monitoring programs. This would provide an integrated, consistent approach to the long-term management of environmental monitoring data. It would enable managers to regularly update and report on local and broader scale assessments of baseline variability and long-term trends in ecosystem health and natural resource condition.

Marine data and information management are central elements to the ongoing success and value of the Kimberley-Browse program. Data must be archived, managed, maintained in perpetuity and made accessible by professionals. For this purpose the Commonwealth has established the Australian Ocean Data Centre Joint Facility. In Western Australia, WAMSI, iVEC (the hub of advanced computing in Western Australia) and WASTAC (Western Australian Satellite Technology and Applications Consortium) have together established a WA Node of the Australian Ocean Data Network for the discovery and access to Western Australian marine data.

The establishment of a marine monitoring and performance assessment system, as described above, would create an enduring legacy for all stakeholders, and for the sustainability of the region.

Objectives:

This theme will:

- provide a fully-resourced data management and information discovery environment;
- establish an integrated, flexible, cost-effective marine observing and performance assessment system for ongoing use by operators, ocean forecasters, resource managers and researchers;
- facilitate forecasts and analyses of marine conditions and their impacts on the environment, offshore operations and coastal communities;
- enable management and coordination of environmental monitoring data from both broader surveillance monitoring (at 'unimpacted' reference locations) and localised compliance monitoring programs; and
- provide understanding of the links between marine climate and ecosystem performance.

Benefits

Benefits arising from theme 5 will include:

- regular analyses and predictions of ocean conditions (such as extreme currents, storm surge and nutrient upwelling) for resource managers, offshore operators and coastal communities;
- high quality information on variability and long-term trends in ecosystems for conservation planning, environmental compliance auditing and fisheries,

aquaculture and tourism management; and

- ongoing improvements in understanding and prediction of regional climate change, its environmental, social and economic implications, and iterative development of adaptive management strategies, based on a growing knowledge base.

In summary, four strategic science themes and a data acquisition, management and delivery theme have been proposed, with stated objectives and anticipated benefits. Table 1 shows that the four strategic science themes encompass seven research areas across which research teams would be formed. These research areas are discussed in greater detail in the Marine Science Case (Appendix 2) and are briefly described here in Table 2.

Table 1: Strategic science themes and their associated research areas

STRATEGIC SCIENCE THEMES	RESEARCH AREAS
Theme 1: **Values and Assets**	• Marine resource and human use inventories • Baseline, natural variability and long term change in marine ecosystems and their drivers
Theme 2: **Sustaining Processes**	• Broadscale climate and ocean processes • Continental slope, shelf and coastal processes • Integrated physical, biogeochemical and ecological modelling
Theme 3: **Threatening Processes**	• Cause-effect pathways, impact prediction and early warning
Theme 4: **Scenario Assessments and Management Strategy Evaluation**	• Planning tools for ecologically sustainable development
DATA ACQUISITION, MANAGEMENT AND DELIVERY THEME	
Theme 5: **Marine Monitoring Network and Performance Assessment System**	• Data acquisition, management and delivery system • Maintaining currency of marine data to ensure continued relevance and effectiveness • Integrating data streams in near real time

Table 2: Research areas and their relevance to marine planning, management and decision-making

1. Broadscale climate and oceanography

To enhance understanding of climate and oceanography of the south east Indian Ocean and their role in driving physical and biogeochemical processes in the embedded Kimberley-Browse marine region. This will lead to benefits in greater understanding and prediction of:

- regional climate variability and long term trends (e.g. cyclone frequency, rainfall, sea level, ocean temperature);
- the connectedness with other regions as a factor controlling / sustaining biodiversity;
- fisheries recruitment processes;
- offshore nutrient sources and biological productivity; and
- the operating environment for offshore infrastructure (e.g. gas production facilities) and maritime operations.

2. Continental slope, shelf and coastal processes

To improve understanding of the oceanography, sediment and nutrient flows, and their role in determining ecosystem structure, function and services within the region. This will provide multiple benefits in relation to:

- biodiversity conservation and management;
- fisheries recruitment processes and management of the fisheries, pearling and aquaculture;
- environmental impact assessment;
- managing catchment land use, river discharge and their impacts on the marine environment; and
- predicting impacts of extreme events (e.g. cyclones) on offshore/ coastal installations; coastal planning.

3. Marine resource and human use inventories

To map and characterise key marine habitats and biological communities, heritage and cultural values, and to document their uses and exposure to human pressures. This will provide benefits for:

- regional marine planning;
- biodiversity conservation management (e.g. identification of marine protected areas);
- management of commercial, recreational and Indigenous fisheries and fish habitat areas;
- environmental impact assessment;
- managing cumulative impacts in multiple use environments; and
- site selection for aquaculture or industry developments.

4. Baseline, natural variability and long term change in marine ecosystems and their drivers

To monitor change in key drivers and environmental condition indicators within the region. This is important in order to understand the relative importance of natural, climate change and human pressures at various scales within the region. Improved understanding of environmental change and the primary causal factors will provide a better basis for many natural resource management decisions, so that they are properly targeted and more cost-effective.

5. Cause-effect pathways, impact prediction and early warning

To improve understanding of the key processes and pathways linking human-induced pressures with changes in the ecology. This will be of significant benefit in relation to:

- understanding the sensitivities of key species to stress, their recovery potential and the resilience of ecosystems;
- identifying early warning indicators of ecological change as triggers for adaptive management;
- developing cost-effective surveillance and compliance monitoring systems;
- environmental impact prediction and management;
- ecosystem-based fisheries management; and
- predicting the ecological impacts of climate change and managing the adaptation of these ecosystems.

6. Integrated physical, biogeochemical and ecological modeling

To model marine ecosystem behaviour (e.g. hydrodynamics, sediment mobility, marine biological productivity and food web interactions) over broader expanses and in greater detail than permitted by available field data, and to predict the effects of changed environmental conditions or human uses.

7. Planning tools for ecologically sustainable development

Improved decision-making will flow from the integration and application of all the research areas to develop decision-support tools for managers and operators. These tools will include:

- predictive models of the region's marine systems, projections of change due to climate-induced and other
- anthropogenic pressures, and estimation of socioeconomic responses to these changes;
- future scenario assessment and management strategy evaluation tools to support sustainable, integrated planning and management in the region.

Transfer of Knowledge

The transfer of research outputs into outcomes of long-term environmental, social and economic benefit is a key strategic objective of this initiative. Delivery of knowledge within the time constraints of decision-making needs is also essential.

Regular interaction between WAMSI, natural resource managers and stakeholders will result in mutual learning and more effective tailoring and application of research outcomes.

Delivery of information will focus initially on areas where decisions are imminent. This focus will broaden as the marine science program progresses, to develop a systematic, predictive and transferable understanding of the region that will be able, with greater flexibility and efficiency, to address a wide range of emerging local and regional needs for policy, planning, management and operations.

Data and information management and retrieval systems will be required as a priority to ensure that existing and new information can be transferred and used effectively by participating research teams, government agencies and private organisations, as appropriate.

Building Capacity

Funding research in the Kimberley Browse Basin will need to be sufficiently high to meet the needs of decision-makers and stakeholders and to enable science to catch-up with existing and emerging pressures. The effort to 'catch up' challenges governments and business to review priorities and increase budgets by committing resources additional to those provided through the usual processes.

Batterham reported that though expenditure on tropical marine science in the north and north west had grown in the nineties, "there is a continuing weighting to north eastern waters" (Batterham 2001). This is changing as government agencies respond to pressures and opportunities in the region.

There are opportunities not only to build a greater capacity for scientific research but also to build capacity among Indigenous people, drawing on their knowledge of their culture and the environment and developing opportunities for training and employment. Capacity building should focus on two priorities: increasing the volume of appropriate scientists through post-doctoral and post-graduate scholarships to produce the next generation of marine scientists and environmental managers and increasing marine resource managers, and land and sea rangers through graduate, diploma and trainee scholarships provided regionally.

There are rare occasions where expenditure must be accelerated to cope with the needs of critical stakeholders in complex situations. Such is the case in the Kimberley now.

Promoting Awareness

Leaders of the stakeholder groups in the Kimberley have been advised of the WAMSI initiative and of the science policy summit. WAMSI itself met local groups in early August and Woodside Petroleum held a workshop in Broome in June. The processes followed by the Deputy Premier's Northern Development Taskforce have also spread awareness of the issues facing decision-makers. Local advocacy and public interest groups have advised the media and leaders in the eastern states of the proposed development in the Kimberley.

Several of the recommendations made in this report are directed at maintaining and increasing awareness of the importance of the region's environmental, cultural and social and economic values. Interpreting and presenting regional marine science discoveries and promoting public awareness through community meetings, website, DVD and organised public visits to research vessels is an integral part of WAMSI's program.

strategic alignment

National Research Priorities

The National Research Priorities highlight areas of particular social, economic and environmental importance to Australia, and where a whole-of-government focus has the potential to improve research and broader policy outcomes.

The WAMSI research proposal is fundamentally aligned with the National Research Priorities for an *Environmentally Sustainable Australia*, and particularly with the following priorities:

- sustainable use of Australia's biodiversity;
- developing deep earth/ocean floor resources;
- responding to climate change and variability;
- strengthening Australia's social and economic fabric;
- breakthrough science;
- protecting Australia from invasive diseases and pests; and
- critical infrastructure.

National Strategies

The WAMSI research proposal is aligned with key priorities from a range of issue-based national policies and strategies, including the:

- National Strategy for Ecologically Sustainable Development (1992);
- National Strategy for the Conservation of Australia's Biological Diversity (1996);
- Priorities for Tropical Marine Research (Australian Chief Scientist report, 1999);
- Arafura and Timor Seas Expert Forum Priorities (2002);
- National Biodiversity and Climate Change Action Plan (2004);
- National Objectives and Targets for Biodiversity Conservation 2001-2005;
- Framework for a National Cooperative Approach to Integrated Coastal Zone Management (2006);
- Marine Bioregional Planning (2006);
- Strategic Roadmap for Australian Research Infrastructure: Exposure Draft (2008); and
- Innovation Review Green Paper (2008).

State Policies and Strategies

The WAMSI research proposal is aligned with key priorities of a range of State policies and strategies, including the:

- Western Australian State Sustainability Strategy (2003);
- Coasts WA: Better Integration (2003);
- Regional Western Australia - A Better Place to Live (2003) ;
- Western Australian Greenhouse Strategy (2004);
- EPA Position Statement on Environmental Protection in Natural Resource Management (2005);
- Better Planning: Better Futures - A Framework for the Strategic Management of the Western Australian Public Sector (2006);
- State of the Environment Report Western Australia (2007);
- 100 Year Biodiversity Conservation Strategy for Western Australia (draft, 2007);
- 2007 Premier's Climate Change Action Statement (2007);
- Northern Development Taskforce (West Kimberley) Statement of Purpose (2008);

- Draft Natural Resource Management Plan for Western Australia (June 2008);
- Indian Ocean Climate Initiative (IOCI), Stage 3, and
- WA Marine Regional Planning initiative (under consideration).

The report has been prepared at the same time as the State government awaits a final report from its North-West Development Task Force. This is expected to make a major contribution to the future of the region.

relevance to decision-making

This report encapsulates nine months of stakeholder consultations to identify the big issues, major decision points and their critical science/information requirements. During this period State and Commonwealth governments have initiated processes aimed at securing positive regional outcomes in planning, conservation, sustainable use, resource development, adaptation to climate change and joint management with Indigenous peoples.

There has been a sharpening of international and local focus on conserving the exceptional natural and cultural values which attract tourists to the region. The rising costs of energy, coupled with growing climate change concerns, has further emphasised the search for discoverable gas reserves and has again raised possibilities for alternative, renewable energy sources which are in abundance in the Kimberley.

Stakeholders at the March 2008 Kimberley-Browse Marine Science Policy Summit concluded that there is a clear need for strategic science to develop a systematic understanding of the region to address the challenges of sustainability and climate change, while at the same time delivering timely inputs into ongoing decision-making. The participants believed that WAMSI was a very good vehicle to facilitate the development of a Marine Science Plan for the region and to commence its implementation as a fully funded activity.

Major regional priorities and associated decisions and management needs which flow from these priorities are presented in Table 3 against indicative timelines. The table demonstrates that decision-makers, end-users and the community will, for the foreseeable future, consistently require up-to-date science-based understandings and data sets that have currency to address the priorities, inform decisions and service needs in the region.

Table 3 also illustrates that the science program can be sensibly delivered in four phases. The phases are designed to respond to immediate information needs, meet ongoing Commonwealth and Western Australian government priorities, and establish the science foundations for longer-term decision-making of benefit to all stakeholders in the region.

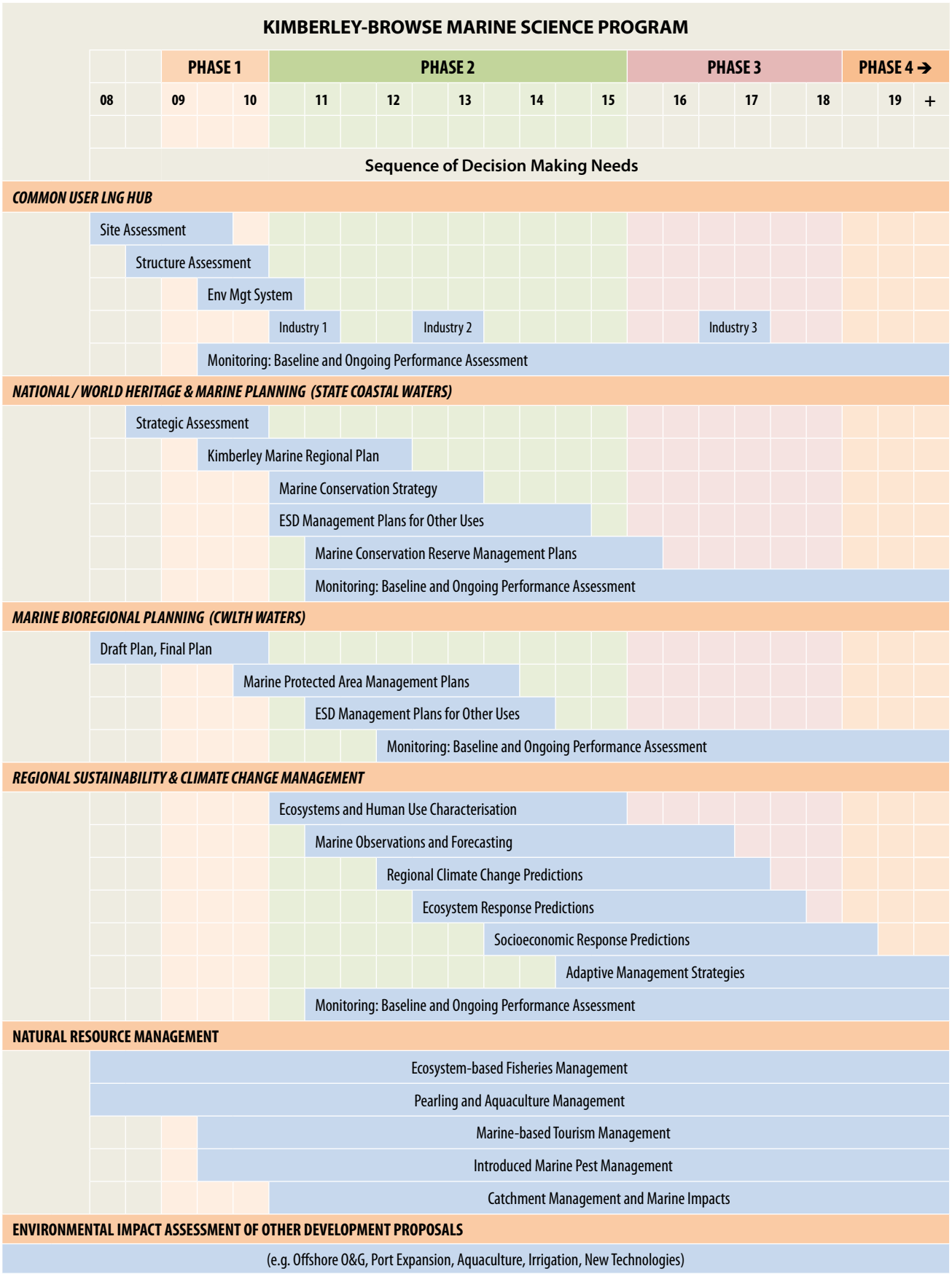
The first phase will begin immediately. The priority for this phase will be timely delivery of critical marine information (habitats, biodiversity and oceanography) from specific areas being considered for imminent government decisions. Detailed research plans for subsequent phases of the program will also be completed during this phase.

The second phase will run from mid-2010 to mid-2015. It will build up a representative understanding of the region's marine dynamics, its ecosystems, and human uses. This information is required for marine regional planning, biodiversity management, recognition of Indigenous values, sustainable, multiple-use of marine-based industries in the region, infrastructure planning, environmental impact assessment and effective environmental monitoring. The marine systems understanding that will be built up during this phase is a fundamental precursor to developing regional management responses to climate change.

The third phase will run to mid-2018, continuing to address the strategic regional priorities. It will provide quantitative understanding of major threatening processes and their potential impacts on marine ecosystems, develop early warning monitoring indicators and predictions of environmental change, assess future socioeconomic responses to change and generate regional scenarios and adaptive management strategies for consideration by policy makers and stakeholders.

The fourth phase will be ongoing. It will provide the science understanding and data to support government and the private sector decisions for sustainability, innovation, evaluation, review and adaptation in the region. This includes performance assessment against regional sustainability objectives; improved meteorological, ocean and long-term

Table 3: Timing of the marine science program phases to address major regional priorities and decision needs



climate forecasts; reassessment and further projection of future scenarios for regional planning and further evaluation of management strategies in response to projected climate change and human use pressures for regional planning.

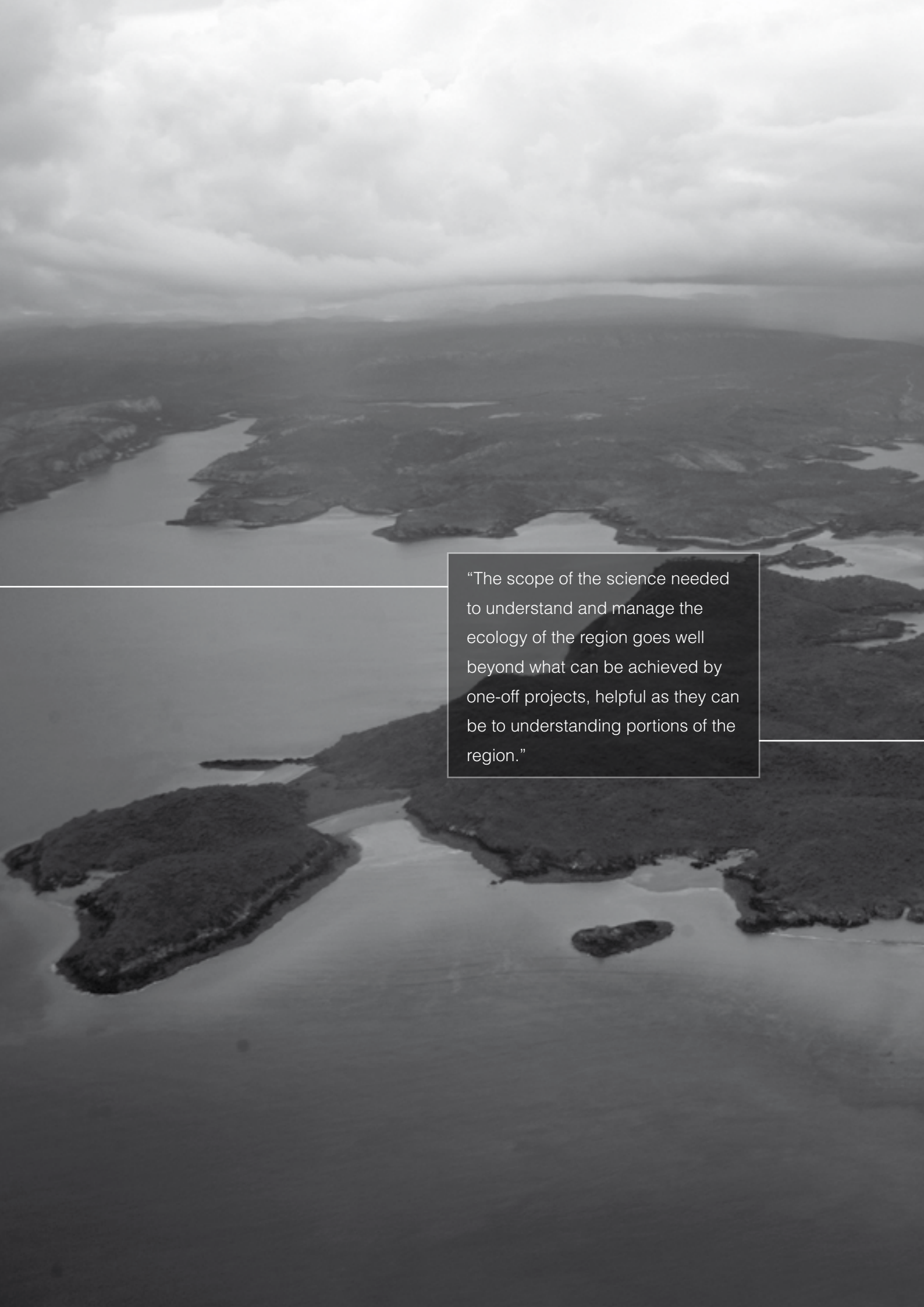
In each phase, there will be a focus on the provision and use of scientific knowledge for decision-making at local, sub regional or regional scale. Table 3 shows the phases and indicates their links to decision needs.

Table 4 illustrates that the relative emphasis between the four strategic science themes (themes 1-4) will vary between the phases, shifting from *description and characterisation* of environments and human uses, to *functional understanding of natural systems, ability to predict* their response to human use and climate change, and ultimately to *assessments* of future scenarios, cumulative impacts and management strategies.

Theme 5 is about establishing data acquisition, management and delivery systems that will greatly enhance the productivity of the strategic science themes and the provision of information and ongoing services to operators, communities, planners and decision-makers in the region.

Table 4. Relative emphasis (in percentages) between the strategic science themes across the four phases of the program

	THEME 1 Values and Assets	THEME 2 Sustaining Processes	THEME 3 Threatening Processes	THEME 4 Scenario Assessment
Phase 1	60	25	10	5
Phase 2	35	40	15	10
Phase 3	25	35	25	15
Phase 4	20	20	30	30



"The scope of the science needed to understand and manage the ecology of the region goes well beyond what can be achieved by one-off projects, helpful as they can be to understanding portions of the region."

areas of focus

Theme 1: Values and Assets

WAMSI can contribute to the implementation of the following initial major priorities for the region. The associated benefits have been outlined in the section on themes and are elaborated in the Marine Science Case in Appendix 2.

Initial Priorities

- support the Commonwealth/State government joint strategic assessment of National Heritage Values in the Kimberley (marine component);
- support the Commonwealth/State government joint assessment of a common-user LNG hub site, assessment of infrastructure layout and formulation of an environmental management system;
- conduct targetted habitat and biodiversity surveys, and establish monitoring programs for baseline, natural variability and long-term change in natural resource condition and human use.

Theme 2: Sustaining Processes

WAMSI can contribute to the following initial major priorities for the region. The associated benefits have been outlined in the section on themes and are elaborated in the Marine Science Case in Appendix 2.

Initial Priorities

Since much of the region's physical and biogeochemical forcings come from large scale ocean-climate processes, early attention should be given to developing an understanding of the region's response to these broader scale influences. Within that regional context, the role of finer scale processes – physical, biogeochemical and ecological - can then be determined for specific areas of agreed high priority.

- initiate an integrated field measurement, data analysis and numerical modelling program to characterise the *physical processes* which govern climate (including extreme events), marine connectivity, tidal dynamics and sediment mobility in the region;
- initiate an integrated field measurement, data analysis and numerical modelling program to investigate the key *biogeochemical and ecological processes* which govern biodiversity, biological productivity and ecosystem services of the region;
- select several locations of agreed high priority for integrated, high resolution research (e.g. locations subjected to human pressure and 'unimpacted' reference locations);
- initiate research to develop interpretation of remote sensing data for marine properties such as circulation, sea level, surface temperature, turbidity and biological productivity, with particular emphasis on shelf and inshore waters.

Theme 3: Threatening Processes

WAMSI can contribute to the following initial major priorities for the region. The associated benefits have been outlined in the section on themes and are elaborated in the Marine Science Case in Appendix 2.

Initial Priorities

- conduct a risk assessment to identify critical cause-effect pathways for priority research;
- identify environmental requirements of key species and communities;
- investigate critical cause-effect pathways to identify practical, early warning indicators of environmental change and sub lethal response indicators in the marine communities;
- develop classifications for habitat mapping, habitat condition and habitat loss.

Theme 4: Scenario Assessments and Management Strategy Evaluation

WAMSI can contribute to the following initial major priorities for the region. The associated benefits have been outlined in the section on themes and are elaborated in the Marine Science Case in Appendix 2.

Initial Priorities

- assemble research on ecosystems (or key ecosystem processes), human use interactions, climate change, adaptive management strategies and monitoring approaches;
- refine the scope and application of this research in consultation with management agencies and stakeholders;
- identify and address all information requirements.

Theme 5: Marine Monitoring Network and Performance Assessment System

WAMSI can contribute to the following initial major priorities for the region. The associated benefits have been outlined in the section on themes and are elaborated in the Marine Science Case in Appendix 2.

Initial Priorities

- establish a data and information management regime that is open-access via the web;
- design and commence implementation of the first module of the marine observation system in consultation with IMOS, participating resource managers, operators and researchers.

delivering results: the resources required

The international, national and State responsibilities embedded in the Kimberley calls out for an organisation capable of effective coordination of marine science across jurisdictions and disciplines. The customary approaches of government will be sorely tried in the Kimberley, a remote and costly region to manage.

The benefits of coordinating research teams to achieve strategic science objectives will far outweigh the benefits of research undertaken into a single issue topic, although the coordination and management costs are likely to be higher. The Kimberley-Browse Basin marine region is extensive, remote and logistically difficult. It generally costs two to three times more to undertake research in the region compared to more accessible and populated regions, for example those around the Great Barrier Reef.

Given the urgency and magnitude of the need in the Kimberley, this is a request for new money to hire new staff and conduct new operations. It is not intended to divert existing WAMSI programs and resources away from marine areas of the central west and south west, where they are currently addressing needs in those regions in accordance with the business case approved by the Western Australian government.

The tables that follow show what is required to deliver outcomes indicated under the strategic science themes and phases outlined in Tables 1 to 3. The estimates are based on the experience of marine researchers in the region, known costs of hiring vessels, the funds allocated to research by INPEX and Woodside noted above and the number of staff needed to conduct research in teams.

Taking into account the remoteness of the Kimberley- Browse marine region, the breadth and sequence of marine science requirements identified, it is considered that such a program would require the following resources over its major stages. Table 5 shows the sums estimated at a broad level for each of the phases.

Estimates of the funding required for this proposed marine science program include $9m to address imminent government decision needs to mid-2010, and $20m per annum for five years, with funding requirements reviewed prior to subsequent allocations being made in 2015.

As a priority, phase 1 will deliver targeted baseline marine habitat maps, biodiversity assessments and oceanographic data in specific areas where government decisions are imminent, including the strategic assessment of National Heritage values in waters of the north Kimberley, the Commonwealth Marine Bioregional Plan and management of areas surrounding a proposed LNG hub location.

Phase 2 will deliver a representative understanding of the region, including its key drivers and dynamics, its values, assets and human uses, and the response of its ecosystems to change.

Table 5: Financial resources for phases 1 to 4

		$m per annum (2008 values)				Years	Total $m
		Salary / On costs	Operations	Science/Business Management	All		
Phase 1	(2009 – mid 2010)	2.4	2.4	1.2	6	1.5	9
Phase 2	(mid 2010 – mid 2015)	9.5	8	2.5	20	5	100
Phase 3	(mid 2015 – mid 2018)	6.5	6	2.5	15	3	45
Phase 4	(mid 2018 onward)	-	-	-	8	-	-

This work will provide a broadscale ecosystem context and, nested within that context, detailed finer scale work on key priority conservation and development areas. The information is required for marine regional planning, management of marine biodiversity, sustainable management, environmental impact assessment, environmental monitoring and adaptive management response to climate change.

Following review of the earlier phases, allocation of further funds would be sought for phase 3 (beginning 2015) to achieve a predictive understanding of major threatening processes and their potential impacts on marine ecosystems, develop early warning monitoring indicators and impact predictions methods, assess future socioeconomic responses to change and generate regional scenarios and adaptive management strategies for consideration by policy makers and stakeholders.

The fourth phase recognises the ongoing need for science, understanding and data to support government and the private sector decisions for sustainability, innovation, evaluation, review and adaptation in the region into the future.

WAMSI's node team leaders provided information on their work in the field. Putting a team on a properly-equipped vessel for three field trips of 15 days duration each will cost about $400,000. Another estimate using divers for a project is estimated at $350,000. A biodiversity project using three post-doctoral students might cost $2m over several years.

Ship time costs range from $6,000 to $35,000 a day, depending on the capacity of the vessel and its suitability for in-shore or deep-water work. Some costs can be mitigated slightly by stationing a vessel on site and moving staff and equipment to it by helicopter. Using specialist equipment such as multi-beam and hyperspectral instruments on lease can add substantially to the costs while accelerating the rate of data collection. Some specialist equipment is in high demand and there are likely to be benefits for research by having an option to charter suitable vessels for specific periods over a five year period and in purchasing appropriate equipment.

On average, a research team can devote up to about 100 days per annum to field work. The remainder of a year is spent in data analysis, report-writing and planning. Some efficiencies in care for specimens and in transport time will be gained should a laboratory be available for use in the Kimberley. Experienced marine science researchers allocate time so that one-third is spent on data acquisition, one-third on analysis and one-third on information synthesis and management.

The strategic science themes and seven research area teams, working in the phases and to the schedule in the Marine Science Case, can be used as a basis to prepare a more detailed operational plan and budget than this project allows. As an indication, each team could consist of six members and operate in a similar way to the present WAMSI nodes. Staffing costs are base salary and on-costs for a team leader and five scientists from relevant disciplines working full-time for a year.

Estimates of resource requirements are indicative only. The costings are based on present day dollar values and costs. No calculations have been made for any costs of development of employment opportunities for Indigenous people. Funds are available from other sources for these important activities.

Proposed Funding Allocation

Assuming a three-way allocation of total funding between salaries/on costs, operational costs and management costs, funds would be allocated approximately in the following proportions as shown in Table 6.

The higher than usual allocation to operations is a reflection of the costs of conducting large scale research in a distant region.

Considering phase 2 (the longest and most intensive period of the program), this level of investment would provide the following capacity.

Salary/overhead costs

A senior scientist (team leader) and five scientists/ technicians would be the minimum requirement for each of the seven research area teams identified in

Table 6: Estimated funding allocation by major activity

Salary/overhead costs for scientific and technical staff	45 %
Operational costs (vessel hire, instrument purchase, supercomputer usage, etc)	40 %
Management costs (program coordination, data management, communications, financial, etc)	15 %

Table 7: Estimated ship time required and costs

Inshore vessel: 8-9 months/yr	250 days @ $10,000 pd	$2.5m pa
Shelf vessel: 2 months/yr	55 days @ $15,000 pd	$0.8m pa
Deep water vessel: 1 month/yr	35 days @ $30,000 pd	$1.1m pa
TOTAL		$4.4m pa

the Marine Science Case. This would cost $9.5m pa, (1 FTE costs on average $225,000 pa).

Operations

Operational costs include vessel hire, equipment purchase/hire, laboratory and storage space hire, travel and other operational expenses. For phase 2 these would total $8m pa across all research areas.

Several vessels with different capacities will be required for inshore coastal, offshore and deep water work. Estimated ship time required and vessel hire costs are summarised in Table 7.

The vessels will be used at this rate for (on average) four years out of the five years of phase 2. This will provide the additional funds required to support equipment purchases and operational expenses.

Funds allocated for equipment purchases/leasing and other operational expenses is $3.6m per annum, plus an additional $4.4m (due to the reduced ship time). On average, that is $0.64m pa for each of the seven Research Area teams, although expenditure would not be distributed evenly across the teams.

Management

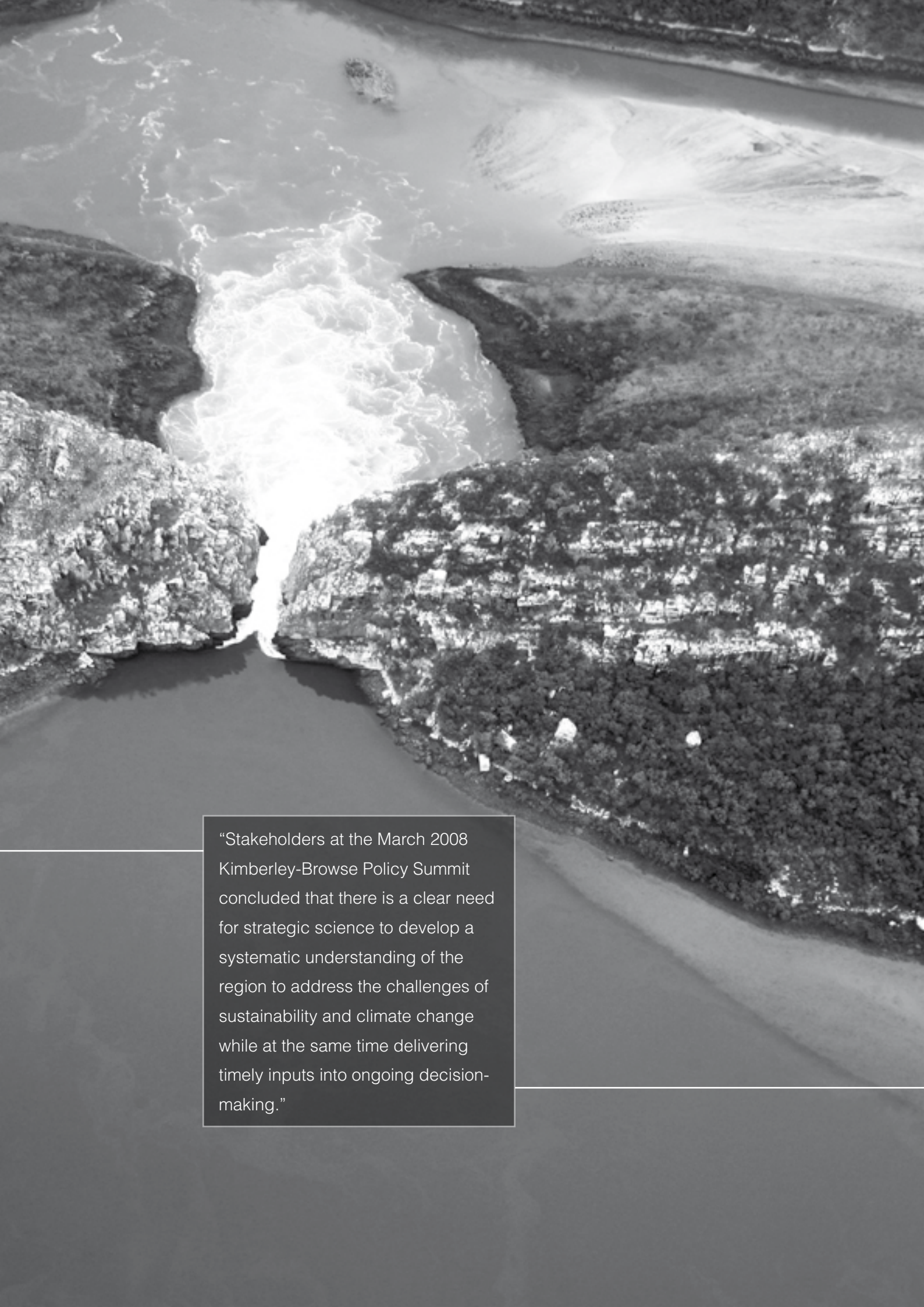
WAMSI Headquarters would require $3.7m in total (over five years) to provide a commensurate level of service to what is provided now, including three dedicated staff on the Kimberley Browse Program (operations manager; data manager; communications officer) and this would cover running the existing WAMSI HQ team for two more years past 2011 when the current WAMSI program is due to end.

Across all of the seven research area teams, housed by the research member partners an amount of $1.8m pa will be required for data management and additional management requirements associated with the Kimberley-Browse science program.

Recapitulating, for phase 2, the expenditure would total $20m pa, consisting of:

- salaries and on costs of the seven research teams (six scientists per team) $9.5m pa;
- data and general management expenses across all of the seven research teams $1.8m pa;
- total operating costs for vessel hire, equipment, lab space, travel and other operating expenses $8.0m pa; and
- WAMSI Headquarters (science coordination, data management, communications, running costs) $0.7m pa.

As indicated in Table 5, the resources required following completion of phase 2 would reduce. The emphasis given to each of the strategic science themes would vary from one phase to the next, as has been demonstrated in Table 4.



"Stakeholders at the March 2008 Kimberley-Browse Policy Summit concluded that there is a clear need for strategic science to develop a systematic understanding of the region to address the challenges of sustainability and climate change while at the same time delivering timely inputs into ongoing decision-making."

co-investment requested

It is proposed that the resources identified in Table 5 be sought as a co-investment in approximately equal proportions from three parties: the Western Australian State government, the Commonwealth government and the private sector. Each sector would then gain a leverage of at least 3:1 on its investment. It also provides a pathway for contributions from other sources including universities, other research bodies and philanthropists. WAMSI's present governance structure and its processes for allocating funds to joint projects, monitoring expenditure and evaluating achievements provides a very good level of scrutiny of investments.

It has been noted already that there are private benefits to be obtained from the proposed research. For this reason, co-investment should be sought with appropriate arrangements for governance that ensure collaborative work is not directed for the sole benefit of private contributors.

There are opportunities for co-investment and the cooperative use of the assets of other organisations which have interests in the outcomes of research in the region. Already researchers advise that the pearl fishing companies and other ship-users collaborate with them and assist in research work.

WAMSI's experience with co-investment is also encouraging for the funding of research. Geoscience Australia, the CSIRO and AIMS have all been involved in co-investment and have indicated they are likely to contribute to further research. Their capacity to do so will be influenced by the development of programs by the new Commonwealth government and the priorities it establishes. Other private sector organisations have indicated their preparedness to contribute funds to research that goes beyond the scope of their immediate interests, seeing this to be both a wise commercial investment and a demonstration of good corporate citizenship. It is recommended that co-investment be expanded to include system-wide projects that will put more localised and any previous research into a regional context.

Commitments that have a bearing on marine science research and its application in the region have been made by the Commonwealth and State governments in recent budget announcements or are likely to be given priority in forthcoming reports such as that on Innovations Australia.

"The decisions facing government and all of the stakeholders overlap jurisdictional and discipline boundaries and require co-operation, co-investment and integrating action by the public, private and non-government sectors."

delivering results: the objectives and the structures

The stakeholders in the Kimberley-Browse marine region share common interests in the achievement of related objectives. The strategic scope of the task is demonstrated in Table 2 and as the work is carried out, it will lead to the delivery of strategic objectives for stakeholders. These are shown in Table 8 below which summarises the strategic outcomes that stakeholders can expect from an integrated and co-invested program of marine science research.

Achievement of objectives requires appropriate governance systems and structures. WAMSI has developed these through the work of its Board of Governors, its system of reporting and evaluating, its system of peer review and the use of integrated research nodes. These strong structures and business processes demonstrate its capacity to achieve the objectives collaboratively with cooperation across disciplinary and jurisdictional boundaries.

The WAMSI strategic plan to 2012 sets targets and outcomes that include contributions to government policy, building a strong marine science capacity and the application of its research results by stakeholders.

WAMSI adds value through a cost-effective science delivery mode; it brings the relevant skills from the multiple partners to work on applied research on major issues before leaders and decision-makers.

WAMSI is providing a platform for coordinating work on the marine impacts of climate change, adaptation and mitigation. WAMSI is a boundary-crosser and is forming new networks to address contemporary problems. Its relevance has been demonstrated by the recent request for it to coordinate research and to provide data for the Northern Development Taskforce as part of government decision-making on the selection of a site for a LNG hub in the Kimberley.

Table 8: Delivering results: stakeholder responsibilities, interests and outcomes

STAKEHOLDERS	STRATEGIC RESPONSIBILITIES, INTERESTS AND OUTCOMES
Commonwealth government	Sound ecological management regimes consistent with international obligations; climate change adaptation; ecologically sustainable development; sustainable Indigenous communities; biodiversity and bio-security and security; emergency response capacity; resource rent.
State government	Sound ecological management regimes; climate change adaptation; ecologically sustainable development; sustainable Indigenous communities; biodiversity and bio-security; security; emergency response capacity; royalties.
Indigenous stakeholders	Sustainable Indigenous communities and companies; employment eg sea rangers programs; climate adaptation capacity; security; cultural protection.
Mining and petroleum companies	Applied science relevant to their activities in the region; certainty in development processes; shared knowledge; climate adaptation capacity; responsible citizenship.
Pearl and other fishers	Applied science relevant to their activities in the region; certainty in uses; climate adaptation capacity.
Tourism operators	Applied science relevant to their activities in the region; certainty in uses; climate adaptation capacity.

WAMSI has demonstrated its capacity to coordinate research projects through its use of research nodes and a growing involvement of scientists in these projects. WAMSI is a newcomer to government, having been foreshadowed in 2005 and launched with resources in 2007 by the Western Australian State government. The organisation was intended to "unlock the economic benefits that the marine environment could provide while ensuring that the marine environment was protected now and for future generations" (press statement 5 June 2005) and has notched up notable successes in a short time.

WAMSI has a focus on training and recruiting fisheries biologists, ecologists, hydrodynamic modellers and climate modellers with a strong quantitative background to undertake statistical analysis and build predictive models of future climate change induced ecological and physical shifts in the Western Australian offshore environments.

Given its relative youth, its projects are yet to be fully realised. However, WAMSI has a strong focus on implementation based on sound inputs. These stress building the "best' project teams with a critical mass of expertise and resourcing. The collective logistic and technical expertises of all the partners are combined across disciplines and jurisdictional boundaries to deliver a holistic research program. This is more effective than research being conducted separately in different organisations. The research program has three integrating science themes:

- ocean system forecasting;
- biodiversity conservation; and
- natural resources development and management.

To achieve this, there are six nodes of research where research projects are communicated to stakeholders and the general public through workshops and public symposia. The first outputs include:

- primary productivity and nutrient cycling on the continental shelf off Perth - this understanding of the marine ecosystem trophodynamics provides the basis and context for all future cause/effect and process related studies. The methodology can be taken to other geographic regions;
- quantification of the warming of the Indian Ocean, with a specific understanding of climate change-related impacts on the Leeuwin Current and Ningaloo Reef system;
- managing fisheries in an ecosystem context additional to focussing on the specific species being targetted;
- impacts of a warming ocean on the marine plants and animals of the State;
- examining with the oil and gas industry, the research areas of interest around defining currents and physical processes affecting offshore infrastructure and coastal regions in the North-West; and
- developing an integrated research program on bio-discovery to enhance prospects in the biotechnology and bio-medicinal sectors.

Two of WAMSI's programs are focused on the establishment of fundamental ecosystem-level understandings of marine environments and especially in the context of current and future climate-change impacts on both the offshore and coastal environments. These have led to the discovery of new kelp forests and new marine bioactive compounds and to the integration of environmental, socio-cultural and economic data in new ways. The sea floor has been mapped for the first time in some areas.

WAMSI forecasts a 1:4 multiplier with a $21m State government investment being turned into an $84m portfolio of projects over five years based on WAMSI member and external contributions.

The tide is turning in the Kimberley Browse Basin.

conclusion

Leaders, government agencies Indigenous people, the private sector, not-for-profit organisations and advocacy and public interest groups have an exceptional opportunity to back the provision of strategic science at a level and in a time frame that will assist the development and management of the region. The next steps require funding, integrative and collaborative science and the delivering of results through a coordinating agency that crosses discipline and jurisdictional boundaries.

bibliography

(A more extensive bibliography is provided in the marine science case report at Appendix 2)

Collins, J. (2008). Marine Tourism in the Kimberley of Western Australia. *Geographical Research, 46 (1)* , 111-123.

Commonwealth of Australia. (2006). *A Guide to the Integrated Marine and Coastal Regionalisation of Australia Version 4.0.* Canberra, Australia: Department of the Environment and Heritage.

CRC Reef. (2003). T*he Value of biodiversity.* Retrieved May 14, 2008, from CRC Reef - Reef Futures: http://www.reeffutures.org/topics/biodiversity/value.cfm

CSIRO. (2007). *Australian offshore mineral locations map.* Retrieved May 12, 2008, from About CSIRO: http://www.csiro.au/resources/ps2et.html

Department of Industry & Resources (2008). *Northern Development Taskforce Terms of Reference.* Perth: Government of Western Australia.

Fletcher, W., & Head, F. (2006). *State of the Fisheries Report 2005-2006*. Perth: Department of Fisheries, Government of Western Australia.

Government of Western Australia. (2006). *Kimberley Economic Perspective. An update on the economy of Western Australia's Kimberley.* Perth: Kimberley Development Commission and Department of Local Government and Regional Development.

Government of Western Australia. (2008). *Integrated Fisheries Management.* Retrieved July 25, 2008, from Department of Fisheries: http://www.fish.wa.gov.au/sec/man/index.php

Inpex Browse Ltd. (2007). *Ichthys Gas Field Development. EIS/ERMP: Environmental Scoping/Guidelines for the Proposed Ichthys Gas Field Development.* Document No. DEV-EXT-RP-0014.

International Coral Reef Action Network. (2006). *Third International Tropical Marine Ecosystem Management Symposium.* Retrieved May 12, 2008, from International Coral Reef Action Network: http://www.icran.org/pdf/ITMEMS%203%20WRITTEN%20PROCEEDINGS%20-%20FINAL.pdf

Jernakoff, P., & Wells, F. (2006). An Assessment of the Environmental Impact of Wild Harvest Pearl Aquaculture (*Pinctada Maxima*) in Western Australia. *Journal of Shellfish Research*, 141–150 .

Joint Ministerial Statement. (2008, February 5). *Big Picture Study of Australia's Kimberley.* Retrieved May 8, 2008, from Minister for the Environment, Heritage and the Arts: http://www.environment.gov.au/minister/garrett/2008/pubs/mr20080205.pdf

National Land and Water Resources Audit. (2001). *Australian Water Resources Assessment 2000*. Canberra: NLWRA.

PEW (2008) *The Weekend Australian*, 12 July 2008; advertisement for Director, Kimberley Conservation Project PEW Environment Group and The Nature Conservancy.

Scherrer, P., Smith, A., & Dowling, R. (2008). *Tourism and the Kimberley coastal waterways. Environmental and cultural aspects of expedition cruising.* CRC for Sustainable Tourism Pty Ltd.

Smyth, D. (2007). *Sea Countries of the North-West.* Report prepared for the National Oceans Office Branch, Marine Division, Australian Department of the Environment and Water Resources.

Woodside Energy. (2008). *EPBC Act Referral of Proposed Action: Browse Upstream Development*. Woodside Energy Ltd, February 2008.

appendices

appendix 1

WAMSI Membership

The vision of WAMSI is to establish a world leading research capability to underpin the conservation and sustainable management of the marine environment and resources for the economic, social and environmental benefit of the State of Western Australia and the nation as a whole.

The current WAMSI member parties are:

Australian Institute of Marine Science

Bureau of Meteorology

Chemistry Centre (WA)

CSIRO - Wealth from Oceans Flagship

Curtin University of Technology

Department of Environment and Conservation (WA)

Department of Fisheries (WA)

Department of Industry and Resources (WA)

Department for Planning and Infrastructure (WA)

Edith Cowan University

Murdoch University

The University of Western Australia

Western Australian Global Ocean Observing System Inc.

Western Australian Museum

WAMSI also has two foundation industry partners:

Woodside Energy Limited

BHP Billiton Petroleum

Interest from potential new parties is welcome.

appendix 2

Marine science case for the Kimberley-Browse marine region

Prepared for the Western Australian Marine Science Institution (WAMSI)
by
Dr Des Mills, Des Mills Marine Environmental Reviews
Professor Mike Wood, School of Business, University of Notre Dame Australia

August 2008

Photographs: **Dr Steve Blake**, WAMSI

vision

The overall vision driving this Marine Science Case is that by 2018 ...

Planning, conservation, sustainable management and utilisation of the Kimberley's unique marine endowment are underpinned by an adequate understanding of the region's natural, cultural and socioeconomic values and systems.

What they are saying

"…our coast and oceans contribute enormously to our identity and wealth. Despite this, much of Australia's ocean territory remains unexplored and poorly understood and this is especially true for northern and north west Australia."

Dr Ian Poiner, CEO,
Australian Institute of Marine Science (2008)

"It was broadly acknowledged that the Kimberley system is the least studied area of the North west Marine Region, largely due to its isolation and the associated difficulties with conducting research there."

Department of the Environment
and Water Resources (2007)

"The Kimberley shelf system is a very unique marine environment nationally and probably also by international standards."

CSIRO (2007)

"There are far greater gaps in knowledge of tropical marine communities, their response to stress, and indicators of their health condition than is the case for temperate marine communities."

Environmental Protection Authority (2008)

contents

executive summary

In December 2007, the Western Australian Marine Science Institution (WAMSI) commissioned the preparation of a marine science case and accompanying business case report to investigate the priority for strategic marine science in the Kimberley and offshore Browse Basin region.

The marine science case (this report) addresses the key issues and big management questions for the conservation and multiple-use of the region and identifies the science that is needed to address these questions. The report focuses on knowledge requirements for decisions of governments and stakeholders from the public and private sectors, the Indigenous people and not-for-profit organisations, as they plan, manage and use the marine environment.

The marine science case report was prepared on the basis of stakeholder input and review of national and international literature. A Kimberley-Browse Marine Science Policy Summit, held on 11 March 2008, brought together stakeholder representatives from the Indigenous, conservation, petroleum, minerals, fishing, pearling and marine-based tourism sectors, research providers as well as Commonwealth and State government agencies. The consultants held further meetings with over 50 stakeholder representatives and WAMSI itself met local groups in Broome.

Marine biodiversity, ecological integrity and cultural heritage values of the Kimberley-Browse marine region are of global significance. Industries such as tourism, fisheries, pearling and aquaculture, which rely on a healthy marine environment, play a vital part in the regional economy and social life. The region has abundant energy and mineral resources and production of offshore petroleum and natural gas can be expected to accelerate rapidly in coming years. Climate change will impact on the ecosystems, the communities and the economy of the region. The extent and severity of these impacts is yet to be fully quantified.

Decisions facing governments and all of the stakeholders in the Kimberley-Browse marine region overlap jurisdictional boundaries and have environmental, social and economic implications. Research is needed that can achieve outcomes in the short term and also build a strategic science base so that ongoing results can be applied to future decision-making and management of the region.

The scope of the science needed to understand and manage the ecology in the face of growing pressures, both from the activities in the region and the effects of climate change, is well beyond what can be achieved by one-off projects. A coordinated, interdisciplinary science program capable of addressing regional to local-scale issues is needed to support better decisions, now and into the future.

Stakeholders at the March 2008 Kimberley-Browse Marine Science Policy Summit concluded that there is a clear need for strategic science to develop a systematic understanding of the region to address the challenges of sustainability and climate change, while at the same time delivering timely inputs into ongoing decision-making. The participants believed that WAMSI was a very good vehicle to facilitate the development of a marine science plan for the region and to commence its implementation as a fully funded activity.

In the past couple of years there have been several reviews of research and knowledge concerning the natural values, ecosystems and human uses of Kimberley near-shore and offshore marine areas. Examples of contemporary research include the Australian Institute of Marine Science (AIMS) study of the Scott Reef and surrounding areas supported by the Browse Basin Joint Venture Partners, WA Museum's work on coastal habitats, research for the pearl fishing industry and INPEX's recent work around the Maret Island. AIMS, Geoscience Australia and the CSIRO have ongoing research programs in the region or do work that is relevant to it. Marine

surveys have been conducted in locations under consideration for a multi-user hub to be the coastal focal point for the processing of liquefied natural gas.

While these research activities are very helpful in documenting portions of the region, they do not provide a coordinated, regional perspective.

This report gives recommendations (at page xi) for a coordinated, strategic marine science program in the Kimberley-Browse marine region to generate and transfer knowledge relevant to contemporary decision needs and strategic regional priorities of leaders and stakeholders.

The overall program would centre around four strategic science themes, which: characterise the region's natural values, assets and human uses; examine how natural processes structure and sustain marine ecosystems; investigate threatening processes and the response of marine communities to stress, and assess future regional scenarios and management strategies to assist planning. An operational data acquisition and information management theme that enhances all of the strategic science themes and provides ongoing services to managers and operators in the region would also be required. Further discussion of the objectives and benefits of the themes and the research areas encompassed is provided in the report. Detailed recommendations for each of the themes may be found at page xi to xiv.

The program is proposed to commence in 2009 and extend over three main phases to mid-2018, with work continuing beyond that to maintain currency of the data sets and relevance of the science to emerging issues and future decisions. Table 5 of the report (page 36) illustrates the alignment of the phases with regional priorities and decision needs. A description of the phases may be found at page 38.

The relative emphasis on the strategic science themes will vary from one phase to another, shifting from description and characterisation of environments and human uses to understanding of natural system processes, ability to predict their response to change, and ultimately to assessments of future scenarios, cumulative impacts and management strategies.

Accordingly, it is recommended that the first phase of the science program deliver targeted knowledge requirements (mainly characterisation of habitats, biological communities and their environmental requirements) for imminent government decisions relating to the management of marine areas encompassing a proposed common-user LNG hub, strategic assessment of the heritage values of inshore marine waters off the Kimberley coast, marine bioregional planning in offshore Commonwealth waters, environmental impact assessment of development proposals (e.g. offshore gas developments), and the management of pearling, aquaculture and marine-based tourism.

Building on this knowledge, it is recommended that subsequent phases of the science program address knowledge requirements for strategic regional priorities, including marine regional planning, maintenance of marine ecosystem integrity and biodiversity, protection of cultural and heritage values, sustainable management of multiple uses, productive marine industries, and regional climate change risk assessments for use in developing adaptive management strategies.

The region is remote, has very strong tidal currents and is exposed to tropical cyclones. Turbid coastal waters and the presence of crocodiles present further difficulties for field research. Selection of cost-effective research methods will be important for this region. Satellite remote sensing and robotic in situ platforms and sensors are able to capture marine data over broad areas and long time spans. Priority should be given to ground truthing and interpretation of data from these sensors. Multi-beam sonar techniques can be used to efficiently map seabed characteristics which provide more readily measurable surrogates for benthic biological communities. This is regarded as a cost-effective way to provide a broadscale understanding of biological resource distributions. These techniques need to be coupled with targeted biological community surveys

which may need to use towed underwater video and drop camera systems.

The region contains a remarkable array of complex habitats with high levels of biological diversity. The shelf edge reef atolls host some of the most spectacular coral reefs in the world. The inshore fringing coral reefs of the northern Kimberley coast are more extensive and diverse than Ningaloo and may well become known as a coral reef province of global significance. The region has a diversity of larger marine animals such as sea turtles, crocodiles, manta rays, whales, dugong and dolphins. Decision-making in the region must be underpinned by high quality, contemporary science at both a regional and local level, to ensure the maintenance of these magnificent natural values while addressing other regional priorities and meeting the needs of stakeholders.

recommendations

Subject to the accompanying business case being accepted, the following recommendations are made for a WAMSI-coordinated marine science program in the Kimberley-Browse marine region.

Strategic Recommendations

1. That WAMSI coordinate a program of strategic marine science in the region to address knowledge requirements for the following regional priorities:
    - marine regional planning;
    - maintenance of marine ecosystem integrity, biodiversity, cultural and heritage values;
    - sustainable management of multiple uses;
    - productive marine industries and innovative marine technologies;
    - land-sea interactions (coastal vulnerability and catchment-marine linkages); and
    - prediction of regional climate change impacts on marine ecosystems and human uses, risk assessments and development of adaptive management strategies.
2. That the WAMSI marine science program addresses knowledge requirements for decision processes affecting the Kimberley-Browse marine region, including:
    - joint Commonwealth/State strategic assessment of a common-user LNG hub, once preferred locations have been nominated by government;
    - subsequent decisions relating to a hub such as its marine infrastructure layout, management of the surrounding marine area and assessments of subsequent proposals for industry collocation within the hub;
    - joint Commonwealth/State government strategic assessment of the Kimberley marine heritage values against criteria for National (and World) Heritage Listing;
    - subsequent decisions related to a Heritage Listed area such as a management plan with strategies for conservation, sustainable use and Indigenous participation, and performance measures and indicators for monitoring to audit achievement of management objectives;
    - integration of Indigenous knowledge to enhance understanding and management of marine and coastal environments;
    - Commonwealth Marine Bioregional Planning (NW Bioregion). Subsequent decisions, also requiring science inputs, would include preparation and implementation of a management plan;
    - environmental assessment of development proposals and environmental management of developments (e.g. offshore gas production, port expansion, changes in catchment land use);
    - establishment and management of a system of marine protected areas; and
    - sectoral management plans for fisheries, pearling, aquaculture, marine-based tourism, and industry, based on ecologically sustainable development (ESD) principles.

General Recommendations

3. That WAMSI, as a matter of priority:
    - identifies and makes appropriate arrangements with organisations which may become new WAMSI research partners, direct research collaborators (working in the region), indirect research collaborators (working on similar problems in other

tropical marine regions), or data providers (e.g. river flow data);

- consults with, informs and seeks permission from traditional owners to conduct research and provides opportunities for Indigenous participation, employment and training;
- identifies and makes appropriate arrangements with other public or private organisations from which specific permission or approvals are required to undertake the proposed research work;
- seeks agreement from industry proponents, operators and other private organisations for access to metadata holdings and to marine data of relevance to WAMSI strategic marine research; and
- continues to strengthen resourcing of marine data and information management systems, with an emphasis on open access knowledge transfer.

Science Recommendations

Specific research recommendations are listed below for each of the major themes included in the proposed science program for the Kimberley-Browse marine region. Implementation of these recommendations should incorporate and build on available, existing data and information.

Values and Assets

4. That WAMSI, through coordination with its research member parties:
    - establishes a live database of historical and current human use patterns and pressures in the region, and assesses future trends;
    - integrates Indigenous knowledge of the values and assets of the region, through consultation with traditional owners and their representatives, and collaboration with relevant researchers;
    - applies cost-effective methods to develop broad scale maps of seabed geomorphology, marine sediments and underlying geology for use as surrogates of habitat and biodiversity distribution. These should be coordinated with targeted surveys of biological communities at selected sites to develop and verify habitat/community auto-classification schemes for use in interpretative mapping;
    - conducts targeted surveys to characterise the marine benthic communities across the region, particularly the marine environments in state coastal waters. These surveys should define the environmental requirements, the dominant species assemblages and distribution of key communities across a representative range of environmental settings. The surveys should include biological sampling for taxonomic analysis;
    - conducts targeted surveys to define and map the regional extent, diversity and variation of fringing coral reef communities in the Kimberley. This would enable these Holocene fringing reefs to be compared with other coral reef systems in Western Australia, Australia and internationally;
    - develops classifications for habitat mapping, habitat condition and habitat loss;
    - identifies critical habitat of threatened marine fauna, including dugong, marine turtle and humpback whale. This should include breeding and feeding areas and the critical seasonal periods for these activities;
    - assesses the population size and distribution and the Indigenous harvest of dugong and marine turtle to understand and manage the populations of these marine fauna;
    - designs programs for monitoring baseline variability and long-term trends in key water column, sediment and biological structure and condition indicators at carefully selected sites and locations, including 'unimpacted' reference areas and nodes of human activity. Sustained, systematic monitoring is required to detect long-term trends associated with

climate variability, climate change, and possible anthropogenic influences;

- establishes baseline data and long-term monitoring to understand the land-sea interaction and the quality of terrestrial runoff entering marine waters off the Kimberley coast;
- initiates research on interpretation of remote sensing data to improve estimates of marine properties such as surface temperature, suspended sediment and chlorophyll concentrations (the latter used as an index of phytoplankton biomass) across inshore and shelf waters of the Kimberley-Browse marine region. Ground truthing and calibration of remotely-sensed ocean colour data in coastal waters is a priority area; and
- incorporates baseline and periodic monitoring of the biosecurity status of the region, and documentation of any new species introductions.

Sustaining Processes

5. That WAMSI, through coordination with its research member parties:
    - gives early attention to developing an understanding of the region's response to broad scale ocean-climate forcings. Within that regional context, investigates and models the role of fine scale processes – physical, biogeochemical and ecological – for selected locations of agreed high priority;
    - initiates an integrated field measurement, data analysis and numerical modelling program to characterise the physical processes which govern climate (including extreme events such as cyclones), marine hydrology, water circulation, marine connectivity among habitats, tidal dynamics, waves and sediment mobility in the region;
    - initiates an integrated field measurement, data analysis and numerical modelling program to investigate the key biogeochemical and ecological processes which, together with the physical processes, govern patterns of biological productivity, biodiversity and resilience of the region's ecosystems. This should be closely linked to the physical processes program;
    - develops an accurate shelf-scale nutrient budget for the Kimberley region;
    - selects several locations of agreed high priority (e.g. proposed development areas, high conservation value areas and other reference locations) for integrated, high resolution modeling and research (e.g. physical energetics, water column variability, benthic habitat and community dynamics, food web interactions and other ecological linkages); and
    - initiates research to develop interpretation of remote sensing data for marine properties such as circulation, sea level, surface temperature, turbidity and chlorophyll, with particular emphasis on shelf and inshore waters of the Kimberley-Browse marine region.

Threatening Processes

6. That WAMSI, through coordination with its research member parties:
    - conducts risk assessments to identify threatening processes and critical cause-effect pathways for priority research;
    - identifies environmental requirements of key species and communities;
    - investigates critical cause-effect pathways to identify practical, early warning indicators of environmental change and sub lethal response indicators in the key species and/or biological communities found in the region;
    - investigates the linkages between coastal water quality and the health and resilience of near shore coral reef ecosystems;
    - develops effective bio-indicators for measuring and monitoring sub-lethal stress in tropical marine organisms arising from poor water quality; and
    - investigates responses in marine ecosystem composition, structure and function to

physical and chemical manifestations of climate change.

Scenario Assessment and Management Strategy Evaluation

7. That WAMSI, through coordination with its research member parties:
    - assembles research relevant to the region on ecosystems (or key ecosystem processes), human uses, climate change, adaptive management strategies and monitoring approaches;
    - determines the scope, application and development of regional scenario assessments and management strategy evaluation in early consultation with managers, stakeholders, researchers and communities;
    - identifies information requirements and addresses these through the broader WAMSI program;
    - in consultation with managers, stakeholders, researchers and communities, maps broad objectives into specific and quantifiable performance indicators to provide a basis for assessment of future scenarios and evaluation of alternative management strategies; and
    - analyses projected social and ecological impacts of multiple-use management strategies in a risk-assessment framework, giving attention to conservation, Indigenous, fisheries, aquaculture, tourism, coastal development and mineral extraction issues, in the context of regional climate change.

Marine Monitoring Network and Performance Assessment System

8. That WAMSI, through coordination with its research member parties:
    - seeks collaboration with Australia's Integrated Marine Observing System (IMOS) and with potential contributors from Commonwealth, State and local agencies, industry, and universities to develop an integrated, flexible, cost-effective marine and coastal monitoring network and performance assessment system for ongoing use by resource managers, operators, ocean forecasters and researchers;
    - contributes to the design and implementation of the system, in consultation with IMOS, resource managers, operators and researchers;
    - promotes the use of cost-effective, new technologies able to capture marine data over broad areas and long time spans (e.g. satellite remote sensing, robotic in situ platforms, wireless sensor networks and novel sensors), and the 'assimilation' of data into ocean simulation models to provide marine forecasting and analysis products;
    - uses data from the network to investigate responses of the region to broader ocean-climate behaviour, and to improve understanding of climate change within the region; and
    - develops a performance assessment system based on monitoring of ecosystem variability and health at selected reference locations throughout the region, and areas under stress, and facilitates linkages with localised monitoring programs (e.g. compliance monitoring).

introduction

Background

The natural, cultural and socioeconomic values and systems of the Kimberley near-shore and Browse Basin offshore marine environments are of regional, national and international significance. They are at risk from the effects of climate change and escalating human uses, but are still very poorly understood.

The Kimberley-Browse marine region hosts a wide range of diverse, unique and productive biological communities. The region is considered to have retained a very high degree of ecological integrity compared with other large tropical marine ecosystems of the world, probably because of its remoteness and low level of past usage. In recent years, however, human activities in the region have increased, and now look likely to accelerate even further.

The awe-inspiring scenic grandeur and recreational and wilderness experience offered by its coastal waters, near-shore islands and offshore atolls has attracted rapidly increasing numbers of tourists to the Kimberley. The region now has commercial and recreational as well as traditional fisheries, and a thriving pearl culture industry, the largest aquaculture operation in Western Australia. Natural gas discoveries in the offshore Browse and Bonaparte Basins amount to more than one third of Australia's total gas reserves. These are of great strategic and economic importance, and the demand to develop these resources is accelerating rapidly.

Development of major coastal and offshore infrastructure (e.g. ports, industry and gas processing facilities), increased shipping, growth in the marine-based tourism and pearling industries, fishing, urban growth and changing land use and hydrology in the Kimberley catchments could combine to place unprecedented pressures on the marine ecosystems of the region and lead to conflicts between uses. These activities and pressures, unless carefully managed, could result in direct and indirect losses of habitat, biodiversity, recreational amenity, cultural use and industry sustainability. Furthermore, climate change effects in the region (e.g. rising sea level, increased sea surface temperature, ocean acidification, changes in the intensity and frequency of cyclones) could pose serious threats to its marine ecosystems and human uses.

Sound planning and management will be required to ensure that its natural values and the resilience of its marine ecosystems are not compromised. Sound planning and management requires good information. This includes an understanding of the natural values and sustaining processes of the environment, of current and projected patterns of human use, and of the implications of future development scenarios from an ecological and socioeconomic perspective. Superimposed on all of this, the best possible understanding of climate change effects on the region, its communities and ecosystems will be needed by decision-makers.

There is broad agreement, however, that the marine environments and ecosystems of the Kimberley-Browse marine region are amongst the *least documented* and most *poorly understood* of any around Australia. For example, there is an urgent need to find out what habitats and biological communities are there, where they are, what condition they are in, what their tolerances are, and how they will respond to the combined effects of human activities and climate change. Improved knowledge and understanding of the marine environment, its values, processes and its interactions with human activities will be required to underpin sound planning and decision-making in this region.

Western Australian Marine Science Institution

In recognition of the above, WAMSI decided to investigate the priority for strategic marine science in the Kimberley-Browse marine region and commissioned the preparation of a marine science case and business case report.

WAMSI provides a significant new approach to ensure that issue-based marine research is undertaken within a strategic framework involving the best scientists and project teams from multiple agencies collaborating within a joint venture.

WAMSI represents the coming together of 16 organisations with expertise in marine research from Commonwealth and State governments, Western Australian universities and the business sector. Each of the members brings to WAMSI a particular array of capacities including research personnel and funding. Other research bodies are likely to join WAMSI over time.

The vision of WAMSI is to establish a world leading research capability to underpin the conservation and sustainable management of the marine environment and resources for the economic, social and environmental benefit of the State of Western Australia and the nation as a whole.

The current WAMSI member parties are:

Australian Institute of Marine Science
Bureau of Meteorology
Chemistry Centre (WA)
CSIRO-Wealth from Oceans Flagship
Curtin University of Technology
Department of Environment and Conservation (WA)
Department of Fisheries (WA)
Department of Industry and Resources (WA)
Department for Planning and Infrastructure (WA)
Edith Cowan University
Murdoch University
The University of Western Australia
Western Australian Global Ocean Observing System Inc.
Western Australian Museum

WAMSI also has two foundation industry partners:
Woodside Energy Limited
BHP Billiton Petroleum

Interest from potential new parties is welcome.

This Report

WAMSI contracted Professor Mike Wood and Dr Des Mills [consultants] to coordinate the preparation of a high-level strategic marine science and business case report for the Kimberley-Browse marine region.

The report was prepared on the basis of stakeholder input and literature search. As an important, early step, the Kimberley-Browse Marine Science Policy Summit, held on 11 March 2008, brought together more than 40 major stakeholder representatives from the Indigenous, conservation, petroleum, minerals, fishing, pearling and marine-based tourism sectors, research providers as well as Commonwealth and State government agencies. The consultants held further meetings with a wide range of stakeholders and WAMSI itself met local groups in Broome.

Drafts of the consultants' report were prepared and reviewed by a stakeholder reference group appointed by WAMSI, with Mr Barry Carbon as independent Chair and members drawn from Commonwealth and State government agencies, Indigenous, industry, marine management, science provider and conservation interests.

The consultants submitted the report to WAMSI in mid-August 2008.

The marine science and business case report deals with:

- the key issues and big management questions for the conservation and sustainable multiple-use of the region;
- the science that is needed to address these questions; and
- the resources required to conduct the necessary research and transfer the knowledge to management agencies and decision-makers.

The aim of the report is to provide a platform for achieving broad stakeholder agreement on:

- a core set of strategic science priorities for the region;

- the tangible benefits of outcomes from the identified science priorities; and
- co-investment strategies and commitments to support the science and effective delivery of the outcomes.

Subject to the accompanying business case being accepted, WAMSI will work with stakeholders and research providers to coordinate the development of a detailed scientific program and the formation of research teams from multiple agencies to conduct the research. WAMSI will ensure that the science program's objectives and outcomes are well-defined and aligned with the priority strategic science needs of stakeholders. WAMSI will audit progress and achievement of agreed science outcomes, support integration of these outcomes to address the strategic issues and management questions for the region, and foster communication of the science in forms useful for decision-making.

Vision

The overall vision driving this marine science case and business case is that, by 2018 ...

> *Planning, conservation, sustainable management and utilisation of the Kimberley's unique marine endowment are underpinned by an adequate understanding of the region's natural, cultural and socioeconomic values and systems.*

the Kimberley-Browse marine region

In this report we refer to the Kimberley-Browse marine region, meaning the marine environments off the northern part of Western Australia (see map on inside front cover), extending:

- alongshore, from the southern end of the Eighty Mile Beach, south of Broome, to the Western Australia/Northern Territory border; and
- offshore, from the high water mark to the edge of Australia's extended continental shelf jurisdiction, including all of the maritime zones declared under the *Commonwealth Seas and Submerged Lands Act 1973*.

The maritime zones, measured from the territorial sea baseline, include:

- state coastal waters from the territorial sea baseline seaward to three nautical miles (nm);
- territorial seas, from the territorial sea baseline seaward to 12 nm;
- contiguous zone, from 12 nm seaward to 24 nm;
- Exclusive Economic Zone (EEZ), extending seaward from 12 nm to 200 nm; and
- the Australian Fishing Zone (AFZ), extending seaward from 3 nm to 200 nm.

The Kimberley-Browse marine region includes seven marine mesoscale bioregions identified in the Integrated Marine and Coastal Regionalisation of Australia (Commonwealth of Australia, 2006). Five of these bioregions are coastal marine (Eighty Mile Beach, Canning, King Sound, Kimberley, Bonaparte, Cambridge-Bonaparte) and two are offshore (North west Shelf, Oceanic Shoals).

The region is influenced by the south east Indian Ocean circulation and the Indonesian Throughflow. It experiences a tropical monsoon climate with two major seasons. Moist winds from the Indian Ocean and southern Asian waters prevail during the 'tropical summer season', giving way to a predominantly south easterly airflow from the continent's interior during the 'dry season'. Sporadic tropical cyclones and severe tropical storms with strong localised winds and heavy rainfall occur during summer. The region is classified as macrotidal, with large spring tidal ranges (up to 11.7 m in coastal waters) and strong tidal currents which mobilise marine sediment, mix the water column and contribute to the generation of internal waves. The shelf and coastal waters receive highly variable freshwater, sediment and nutrient runoff from the mainland Kimberley river catchments.

The Kimberley-Browse marine region includes areas of abyssal plain, a deeply incised continental slope, a broad continental shelf with atolls and many islands, and a varied coastline with rocky shores, fringing coral reefs, sandy beaches, sand flats, seagrass meadows, mangrove communities and mud flats which are often found in the more sheltered embayments and estuaries.

The region has highly diverse marine and coastal habitats and biological communities which take advantage of a wide variety of geomorphic and environmental settings. It is thought to have retained a high degree of ecological integrity compared with other large tropical marine ecosystems of the world. While many species are also present in other parts of the Indo-Pacific tropical region, a significant portion of the demersal and benthic fauna in particular are relatively unique to the region. The region is important for whale migration, resting and calving (Jenner et al 2001). It provides nursery and feeding areas for marine mammals such as whales, dugongs and dolphins and nesting areas for turtles. It is internationally recognised as a very important staging area for migratory birds.

The region currently has a low population base with relatively few towns and settlements, but is growing rapidly. Aboriginal people comprise almost half of

the current population. The Indigenous cultural values are unique assets of the region.

The Kimberley-Browse marine region currently supports a range of industries including marine-based tourism, commercial fishing, pearling, aquaculture and mining. The region's ports ship cattle and mineral products, support large cruise ships, charter, pearling and offshore supply vessels, and import commodities. There is considerable potential for further growth in the size and scale of nature-based tourism and associated commercial enterprises as the iconic status and beauty of the Kimberley coastal and offshore environments becomes more widely known. Very large reserves of petroleum and gas have been discovered at offshore locations in the Browse and Bonaparte basins and other offshore fields. Known gas reserves in the Browse Basin alone exceed 31 trillion cubic feet (Government of Western Australia 2006).

Why is this Region Unique?

The seas between the north west coast of Australia and the Indonesian Archipelago are strongly influenced by the Indonesian Throughflow, the world's only low latitude exchange of water and heat between oceans. This area is considered to be very important for understanding the global climate system and is known to influence rainfall across southern and western Australia as well as the variability of the Leeuwin Current.

The Kimberley Browse marine region has the world's most macrotidal, tropical shelf sea and it is one of the most cyclone-prone regions of Australia. These sources of energy – one predictable, the other sporadic – have a major influence on the marine ecology and human uses of the region.

The Kimberley-Browse marine region contains a remarkable array of often complex habitats which support high levels of biological diversity. The shelf edge reef atolls host some of the most spectacular coral reefs in the world. The coral fauna of platform fringing reefs and rocky shores of the Kimberley coast is also remarkably rich, but quite different in community composition and structure to reefs developed in clearer water and less extreme tidal conditions further offshore. In addition to the diversity of corals, fish, molluscs and other invertebrates, the region has a diversity of larger marine animals such as sea turtles, crocodiles, manta rays, whales, dugong and dolphins.

The scenic beauty, recreational and wilderness experience offered by its coastal waters, islands and outer shelf atolls is attracting an ever-increasing number of visitors and tourists to the Kimberley.

Extending to the north west boundary of Australia's territorial jurisdiction, the Kimberley-Browse marine region is a highly strategic area for defence preparedness, customs surveillance, border control and security for its offshore resource developments. The large tides and tidal currents of the region provide an important potential source of renewable energy. Each of these strategic functions along with other maritime operations such as shipping, commercial fishing, marine-based tourism, sea search-and-rescue (and other emergency operations) will benefit from improved understanding of the region and enhanced forecasting of weather and ocean state behaviour.

regional issues and human uses – current and future

Overview

This section describes major issues and human uses of the Kimberley-Browse marine region, their significance, interactions and potential impacts on the environment.

It is of concern that, for some of the uses, there is limited information on the local environmental values and attributes which could potentially be affected, and a lack of systematic monitoring of human pressure and environmental condition.

Furthermore, the lack of data on broadscale habitat and biodiversity distributions and the lack of understanding of processes which either sustain or threaten biodiversity means that it is not possible to fully assess the wider ecological implications of site selection, operations and uses; nor is it possible to estimate the overall level of activities that would be consistent with sustainable use and maintenance of the natural values of the region.

Conflicting demand for access and interactions between uses are already being experienced in coastal areas and offshore atolls of the region. Consideration needs to be given as to how the various sectors and interests fit into an overall regional multiple-use plan including Indigenous use and access, conservation, pearling, aquaculture, maritime and industry infrastructure.

There is an important need to develop the necessary science understanding to underpin ecosystem-based planning and management for the multiple uses of the region. Identifying the key human uses and management questions of concern will help to inform the science needs and priorities. The need for this understanding becomes even more urgent as governments, managers and users search for adaptive management strategies to cope with the encroaching effects of climate change in the region.

At the 2006 International Tropical Marine Ecosystems Management Symposium (International Coral Reef Action Network 2006), 324 of the world's leading tropical ecosystem scientists and managers, from 45 countries, stated that ...

> *"Climate change is now recognised as one of the most serious long-term threats to the biodiversity and services provided by tropical marine ecosystems."*

Significantly, they went on to state that ...

> *"Managers can take action to reduce the impacts of climate change in tropical marine ecosystems."*

Conservation of Biodiversity

Biodiversity is the variability within and among genes, species and ecosystems. It covers marine, terrestrial, subterranean and aquatic life and implies a highly complex system of interacting living entities.

Biological diversity fosters a resilience that provides the ability for ecosystems and species to cope with change, fluctuations and disturbances, either natural or human induced. It also allows for evolutionary processes to occur, including speciation brought about from genetic variation and ecological adaptation. Hence, the notion of biodiversity is greater than the sum of its parts and the range of services and benefits that flow from it are greatly enhanced by this intactness (Department of Environment and Conservation 2006).

It is marine biodiversity that underpins marine-based industries and human use values such as fishing, tourism, bioprospecting (for useful compounds found in marine organisms), Indigenous use, education, research and aesthetic enjoyment.

Marine biodiversity confers many indirect (but essential) benefits such as ecosystem function and resilience, storage and recycling of nutrients, maintenance of nursery habitats for migratory fauna, maintenance of fish stocks, shoreline/coastal protection and visual amenity (CRC Reef 2003).

Marine biodiversity provides a wide range of options for human appreciation and use. It has been recognised nationally and internationally for its intrinsic value, and a value that must be passed on to following generations.

It would clearly be impossible to manage the conservation of every marine species individually, although some species warrant that attention. Hence, there is also a need to focus on identifying, protecting and managing potentially threatened systems at a variety of scales, from habitats and communities through to larger scales such as 'ecosystems' and bioregions.

Threats to marine biodiversity occur at very different scales ranging from local and regional disturbances to the worldwide impacts of global warming. Marine biodiversity may be threatened by direct disturbance (e.g. benthic trawling, offshore mining), increased sediment and nutrient loads (e.g. discharge from river catchments), overfishing and marine pest infestations, ocean warming and acidification, and increased sea level. Systems already under stress from one threat tend to become more susceptible to stresses from other threats.

Broadscale assessment of the level, distribution and role of marine biodiversity is a developing area of marine science which is urgently required for marine planning, conservation and management. The use of more readily measurable surrogates for benthic biological communities is regarded as a cost-effective way to provide a broadscale understanding of marine ecosystems and their biological resource distributions (Bax & Williams 2001). Targeted biological community surveys, specimen collections and taxonomic analyses have an essential role to play within the context of these broadscale assessments (Ponder, Hutchings, & Chapman 2002).

Mesoscale bioregions have been defined for the Kimberley-Browse marine region through the Integrated Marine and Coastal Regionalisation of Australia (Commonwealth of Australia 2006) and research is underway (Brewer et al 2007; Potter et al 2008) to determine smaller scale ecological units to assist conservation management and environmental protection. This work has revealed numerous information gaps required to complete this task in a definitive manner and, in any case, has focused primarily on Commonwealth waters.

The Commonwealth government uses the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) to list, protect and manage threatened, migratory and marine species. Under the EPBC Act it manages an estate of marine protected areas (MPA). Within the area of interest to this report are the:

- ***Ashmore Reef National Nature Reserve***, located in the Timor Sea about 610 km north of Broome. Ashmore Reef lies at the western extremity of the Sahul Shelf where it is one of only three emergent reef systems;
- ***The Cartier Island Marine Reserve,*** which includes Cartier Island (about 45 km from Ashmore Reef) and the surrounding reef, including the substrata to a depth of 1000 metres below the sea floor; and
- ***Mermaid Reef Marine National Nature Reserve*** which is located about 300 km west of Broome. The total area of the Marine National Nature Reserve is 53,984 hectares and the declaration includes the seabed and subsurface to a depth of 1000 metres. Mermaid Reef is the most north easterly atoll of the Rowley Shoals.

The Commonwealth government is implementing a series of marine bioregional plans for Commonwealth marine waters, including one for the north west of Australia (Department of the Environment, Water, Heritage and the Arts 2008). These plans are designed to consolidate available knowledge about marine ecosystems and human activities in the regions, and provide an improved basis for decision-making about the conservation and use of the Commonwealth's marine estate.

In Western Australia, the Department of Environment and Conservation (DEC) has responsibility for protecting and conserving the state's environment. The State government has designated DEC as the

lead state agency for monitoring the establishment and progress of a long-term state biodiversity conservation strategy (Department of Environment and Conservation 2006). DEC is responsible for implementing management plans for marine wildlife (e.g. whale shark), threatened marine fauna (e.g. turtles, dugong) and the state's marine conservation reserves. The WA Department of Fisheries has a role in managing and conserving 'fish and fish habitat' .

The WA Environmental Protection Authority (EPA) prepares environmental policies, strategic environmental advice and environmental impact assessment recommendations for consideration by government.

Within the area of interest to this report is:

- ***The Rowley Shoals Marine Park,*** comprising the Clerke and Imperieuse Reefs which lie in State waters, approximately 300 km west of Broome.

The Commonwealth and Western Australian governments have announced a joint strategic assessment of the values of terrestrial and marine areas of the Kimberley for national or international heritage listing (Joint Ministerial Press Statement 2008).

Marine-based Tourism

There has been dramatic growth in coastal and marine-based tourism in the Kimberley over the past 10-15 years. Commercial tourism businesses include fishing boat charters, whale watching expeditions, remote coastal camps, extended Kimberley cruises, scenic coastal flights and offshore diving expeditions. The longer range cruises extend right around the Kimberley coast and the diving expeditions range 300 km offshore to the Rowley Shoals.

Estimates from within the Kimberley indicate that marine-based tourism generated $100m in 2005 (Collins 2008). In 1996 six vessels offered marine tourism packages along the Kimberley coast: by 2007 the number of vessels had grown to 27. Coastwatch vessel sightings within state coastal waters increased from 3296 vessels in 1996 to 9256 vessels in 2004. The Broome Port had 16 bookings in 2007 for the expedition cruise vessel Orion as well as bookings for Coral Princess, Oceanic Princess, Saga Ruby, Silver Cloud, Pacific Princess and Europa (Department for Planning and Infrastructure 2006).

Collins (2008) found that marine-based tourism visits occur at approximately 216 locations throughout the region. Sites of greatest interest include places to fish, areas for sightseeing and secluded locations for general relaxation. Approximately 20 per cent of these identified sites are used for fishing. The best known fishing sites include the 10 major river mouths in the region and distant offshore reefs (Collins 2008). Approximately 30 per cent of the 216 sites visited are within areas recommended by Wilson (1994) as candidate areas for marine conservation, and use of natural resources in these areas has risen steadily since 1996.

If tourist operations are not sustainably managed, they can exert pressures on the environment which degrade the very qualities that attract people to the area. Such pressures can result from overfishing, unauthorised shell and specimen collection, physical disturbances including reef walking and anchor drag, poor waste management practices, and introduction of marine organisms from ballast water discharge or dislodgement of hull fouling organisms. These pressures can give rise to impacts including depletion of marine resources, degradation of culturally significant sites, coastal erosion, habitat damage, loss of biodiversity, marine debris and pollution.

Benchmark studies are needed to determine the types, size, location and timing of tourist activities and the distribution of natural assets (e.g. turtle nesting beaches) within the area of influence of these activities. The cause-effect pathways between likely stressors and their potential impacts on the assets need to be understood. There is also a need to consider issues such as resource usage, access, and the relationships and linkages of these tourism activities to other uses (e.g. conservation, Indigenous or pearling). Periodic monitoring is required to gain a greater understanding of the effects of tourism on the environment and its interactions with other users. This understanding can be used to assess a range of future growth scenarios to predict what the key areas and impacts of tourism are likely to be, and

how they will affect the environment, the industry itself, and other uses.

If local tourism continues to grow at current rates, unplanned, unmanaged, uncontrolled, then it will not be sustainable (Collins, 2008). It is important to understand, plan and manage tourism activity in the region for the long-term ecological, economic and social good.

A substantial and very important technical report prepared for the CRC for Sustainable Tourism on tourism and the Kimberley coastal waterways by Scherrer, Smith, & Dowling (2008) concludes that there is an "urgent need for an improved governance framework and the development of appropriate statutory and non-statutory mechanisms to facilitate accountability in coastal planning and development of the Kimberley coastal area."

This comprehensive report contains information on current tourism operations, the biological and physical impacts of expedition cruising, the views of stakeholders including traditional owners and the management issues raised by them and other stakeholders. It makes recommendations for legislative review and provides protocols for engaging with Indigenous Western Australians.

Pearling and Aquaculture

Aquaculture along the Kimberley coast is dominated by the production of pearls from the species *Pinctada maxima*. Other aquaculture activities are focused on production of barramundi**,** redclaw and trochus (for reef enhancement), and on developing the black tiger prawn industry and Indigenous aquaculture (Fletcher & Head 2006). The Department of Fisheries advises that, along the Kimberley coast in 2008, there were 89 pearl farm leases status 'Leased', occupying approximately 58,271 hectares and 40 aquaculture sites status 'Licensed' occupying approximately 30,243 hectares.

The Kimberley's pearling industry, with an estimated annual worth of up to $130m, has three main components – the collection of pearl oysters from the wild, production of hatchery-reared pearl oysters and grow-out of pearls on pearl farm leases. Sheltered marine waters are ideal locations for pearl oyster farms. Oyster racks are suspended from a network of buoyed ropes firmly anchored to the seabed. Good tidal movement is required to maintain a natural supply of plankton and to flush away wastes discharged by the oysters as well as marine fouling organisms so that the chemical and physical state of the sea bed is not affected.

Jernakoff & Wells (2006) report an analysis of the main potential environmental and ecological risks that arise from the various activities carried out by the *P. Maxima* industry. Of the 23 risks identified, none were assessed as high and only three as moderate risks, namely the introduction of disease from seeding, the attraction of other fauna and the introduction of exotic organisms. All of these risks were considered to be manageable.

Introduction of marine pests through ballast water discharge or dislodgement of hull fouling is a risk, both for the surrounding environment and potentially to the pearling operations themselves (e.g. boring sponge). In addition to general coastal shipping, the pearling industry uses boats (which take ballast water) to transport shell between sites in the Northern Territory and Western Australia. More rigorous management arrangements will be put in place in the next few years when *Biosecurity and Agriculture Management Regulations* come into force. To be effective, these regulations will need to be supported by regular monitoring of the biosecurity status of the region, and documentation of any new species introductions.

A four year research collaboration between the Pearl Producers Association, the University of Newcastle and the fisheries consultancy Biospherics is monitoring the environment around three Kimberley pearl farms and comparing the ecology of those areas to nearby reference locations to determine whether there is an environmental disturbance arising from pearl cultivation. This work is supported by the Commonwealth government Fisheries Research and Development Corporation (Pearl Producers Association 2007).

The Department of Fisheries has identified that the Kimberley has significant potential for diversifying aquaculture and is supporting commercial interest in the region through the Broome Tropical Aquaculture Park. In addition, hatcheries and trials are underway to assess a range of fish species including barramundi and aquarium fish (Government of Western Australia 2006).

The Kimberley looks likely to experience significant growth in seacage fish aquaculture (e.g. barramundi). Unlike the pearl industry, seacage fish culture requires artificial feeding. Artificial feeding introduces nutrients and particulates to the area which, together with fish faecies, may have the potential to modify the seabed and benthic communities. Waste feed material may attract marine fauna to the area and this may increase the risks of disease transfer and of marine mammal entanglements. Escape of cultured fish from the seacages may impact on the genetics of wild, endemic fish populations.

Deterioration in near-shore water quality due to activities or uses in the catchment or local sources could affect the production and profitability of the industry.

It is clear then that site selection, risk assessment and management for sustainable pearling and aquaculture operations requires knowledge of the hydrodynamics, seabed substrates and habitats within and surrounding the lease site. Quantitative baseline water quality, sediment and biological surveys within the area of influence of operations, and at appropriate reference sites, need to be followed up by regular monitoring to determine seasonal and inter-annual variability as well as long-term trends.

The provision of broad-scale, strategic baseline data for these environmental variables and long-term time-series data at appropriate reference sites would, in conjunction with proponents' site specific monitoring requirements, be of great benefit for future planning of the pearling and aquaculture industries. It would provide a stronger base for decisions in respect to individual lease and licence applications, and it would result in more cost-effective monitoring programs for operators.

Fisheries

The principal wildstock fisheries in the region focus on finfish, particularly the high-value emperors, snappers and cods. There are a number of limited-entry trawl fisheries for prawns. There are also significant fisheries for Spanish mackerel, barramundi, threadfin salmon and shark. In addition, species, such as barramundi, tropical emperors, sea perches, mangrove jacks, trevallies, sooty grunter, threadfin, mud crabs and cod can be found in the creek systems, mangroves, rivers and beach areas. The total live catch for the 2004/05 season was 2,426 tonnes, estimated to have a value of $13.5m. Finfish and prawns contribute 98 per cent of the value of the catch in the Kimberley (Government of Western Australia 2006).

Commercial fisheries in the region which are managed under State legislation include the:

- Broome Prawn Managed Fishery;
- Kimberley Prawn Managed Fishery;
- Kimberley Gillnet and Barramundi Managed Fishery;
- Northern Demersal Scalefish Managed Fishery;
- Mackerel (Interim) Managed Fishery;
- Northern Shark Fisheries;
- Pearl Oyster Managed Fishery; and
- Beche-de-mer Fishery.

Details for each of these may be found in the WA State of the Fisheries Report (Fletcher & Head 2006).

Other commercial fisheries relevant to the region are controlled by the Commonwealth in accordance with Commonwealth fisheries legislation. Details of these may be found in (Commonwealth Government 2007). They include the:

- Northern Prawn Fishery;
- North West Slope Deepwater Trawl;
- Southern and Western Tuna and Billfish Fishery;

- Southern Bluefin Tuna Fishery; and
- Western Skipjack Tuna Fishery.

Under a Memorandum of Understanding between the Offshore Constitutional Parties, representatives of the Commonwealth, Queensland, Northern Territory and Western Australia must meet at least once per year to discuss management of northern fish stocks subject to their respective Offshore Constitutional Settlement agreements and Joint Authority arrangements.

Recreational fishing is experiencing significant growth in the region, with a distinct seasonal peak in winter when the local population is swollen by significant numbers of Australian tourists travelling independently through the area and visiting particularly the coastline around Broome. Because of the high tidal range much of the angling activity is boat-based, with beach fishing limited to periods of flood tides and high water. Species important to recreational fishers in the more inshore habitats of the region include Queenfish, King salmon and barramundi (Government of Western Australia 2006).

In addition, Collins (2008) found that chartered recreational fishing occurs at approximately 45 locations regularly visited by charter vessels. The best known fishing sites include the 10 major river mouths along the Kimberley coast and distant offshore reefs at Scott, Seringapatam, Ashmore and Cartier.

There are a number of significant issues facing the management of fish resources in the region.

Pressure on fish stocks in international waters near Australia will continue to increase with the steady expansion of consumer demand in developing countries where disposable income and population are growing strongly. The Kimberley-Browse marine region is increasingly coming under threat from international poaching (particularly for sharks) and illegal fishing in offshore regions. The region may also be affected indirectly as a result of its marine connectivity with south east Asian waters where fish populations are already under intense pressure.

Potential climate change impacts on the species' abundance within this region are of concern, but there is insufficient information at present to assess this risk.

Other risks for the fisheries of the region include the potential for transfer of diseases, introduction of exotic pest species, inshore impacts from coastal developments, changes in catchment discharge, and competition for access to inshore marine areas.

Significant impacts to epibenthic invertebrate communities (e.g. sponges) occurred in some areas subjected to past trawling. These communities have very long recovery times. New technologies can now be applied to better characterise the seabed and inform regulators so that trawling is not allowed in areas where unacceptable impacts would occur.

Allocation of access to inshore fish resources between commercial recreational and Indigenous sectors within sustainability limits is another significant challenge for fisheries managers.

These management challenges are being addressed. For fisheries management in Australia, whether administered at a State or Commonwealth level, there is a requirement for all export-based fisheries to submit applications under the Commonwealth government's guidelines for sustainable fisheries. Individual fishery status reports are prepared annually using an ESD reporting approach that has enabled all significant commercial fisheries to undergo assessment and achieve environmental certification under the Commonwealth government's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The individual fisheries status reports cover a range of issues, including breeding stock status non-retained species, habitat and ecosystem effects, target catch (or effort) range, and 'external factors' beyond the control of fisheries managers**.** They report performance of the relevant fisheries against specific performance measures developed during the EPBC Act assessment process.

Fisheries management research is currently investigating ecosystem-based fisheries management approaches involving multi-fisheries assessments (Fletcher 2006). Protecting fish habitats has become a core function of fisheries management.

Integrated Fisheries Management (IFM) is a framework designed to address the growing

competition for fish resources between commercial, recreational and Indigenous fishers (Government of Western Australia 2008).

A draft Indigenous Fishing Strategy (Department of Fisheries 2003) was developed following extensive consultation with Indigenous people and other key stakeholders. Key recommendations include the establishment of an Aboriginal Fishing Fund for the acquisition, through the market, of commercial fishing licences, the recognition of customary fishing and an Indigenous Fisheries Ranger program. The intent of the strategy is to ensure that fisheries management includes and recognises Indigenous people's use of fish for food, cultural reasons and for economic development.

Petroleum and Gas

The region has large reserves of petroleum and gas at offshore locations in the Browse and Bonaparte basins and in other offshore fields. The Browse Basin alone has 31 trillion cubic feet of gas. It is likely that rapid development of the Kimberley's offshore reserves will occur over the next few years, necessitating infrastructure development to service the industry. The operating lifetime of the known fields is likely to be well over 40 years, with a high probability of further significant finds in the region (Government of Western Australia 2006).

Woodside Energy Ltd, as operator of the Browse Joint Venture (JV) is proposing to develop the Torosa, Brecknock and Calliance gas fields located approximately 290 km off the Kimberley coast in the Browse Basin (Woodside Energy 2008). While these fields are, in the main, situated in deep water (400-700 m), part of the Torosa field lies below the emergent shelf atolls of Scott Reef. It is proposed that offshore operations will collect the reservoir fluids, separate out gas condensate for direct loading to tankers for export, and process the gas such that it can be transported via subsea pipeline to an onshore LNG facility. The Commonwealth and Western Australian governments will be assessing this project proposal under a coordinated parallel assessment process. The offshore component of this project will be assessed in the first instance, and the near-shore and onshore components will be assessed once there is a decision on a preferred LNG processing location.

Over its full life, the project is estimated to have a value of A$65 billion in Gross State Product to WA and direct combined revenue (in current dollar terms) to the Commonwealth and State in the order of A$33 billion over the life of the project.

INPEX is proposing to develop the Ichthys Field (also located in the Browse Basin) to produce condensate, Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) for export (Inpex Browse Ltd 2007). The proposal includes the transport of gas from the Ichthys Field via a subsea pipeline to onshore processing facilities.

Shell has submitted to the Commonwealth Government a proposal for a 3.5 million tonne per year offshore floating LNG plant to process and export LNG from the Prelude gas field which lies 450 km north east of Broome in the Browse Basin, wholly within Commonwealth Waters.

The Northern Development Taskforce is responsible for identifying preferred options for the location of a *Common-User LNG hub Precinct* for the Browse Basin. It is anticipated that this will occur during October 2008. This will be followed by a joint State and Commonwealth strategic assessment of the preferred options (Joint Ministerial Press Statement 2008) which is scheduled for completion in mid-2009. The proposed LNG hub precinct would have the capacity to process and export gas from several major offshore developments and to provide a natural gas feed for collocated industries.

Design, installation and operation of offshore petroleum and gas production and pipeline facilities requires a detailed and predictive knowledge of meteorological and oceanographic conditions, including extreme events such as cyclonic winds and waves, together with an understanding of the geotechnical properties and stability of the sea floor.

Environmental issues associated with offshore operations may include physical and seismic

disturbances, drill cutting releases, produced formation water discharges, unscheduled failures or spill events. These disturbances can potentially have adverse direct or indirect impacts on pelagic and benthic communities. For onshore processing and export facilities, the potential environmental issues include construction and workforce impacts, dredging operations, the infrastructure footprint (changes to coastal form and bathymetry), waste water discharges, unscheduled leaks and spills, noise, vibration, and light spill. These disturbances can impact on water and sediment quality, benthic habitats, marine biological communities and migratory marine fauna.

Minerals

In 2004/05 the top five mineral and petroleum commodities in the Kimberley were diamonds, nickel, iron ore, crude oil and rock (Government of Western Australia 2006). High grade iron ore is mined on Cockatoo and Koolan islands in the Buccaneer Archipelago. Diamonds, nickel and zinc/lead deposits are mined inland at Argyle (diamonds), Sally Malay (nickel) and Cadjebut (zinc/lead).

The Australian Offshore Minerals Location Map (CSIRO 2007) reveals continued exploration for marine diamonds in the Joseph Bonaparte Gulf, to the north of Wyndham, and that there are deposits of mineral sands in King Bay and Pender Bay. Other iron ore deposits are being surveyed on Irvine Island. Bauxite reserves occur in the Mitchell Plateau and Cape Bougainville areas.

Bulk nickel/copper/cobalt concentrate is transported by road to the Port of Wyndham for export. Lead and zinc concentrates are barged from the Port of Derby (Government of Western Australia 2006).

Export of minerals requires port infrastructure, stockpiling and ship loading. There is potential for release of particulates and toxicants into the marine environment arising from drainage and airborne dust emissions from stockpiles, as well as spills and dust during ship loading . Ship movements in inner port areas re-suspend natural and introduced particulates, increasing turbidity. Shipping carries with it the risk of marine pest introductions which can have serious consequences both for ecosystem health and commercial uses. Submarine mining disturbs the sea floor and impacts on benthic habitats and communities. It re-suspends sediments, increasing turbidity and reducing light available at the sea floor.

Catchment Land Use, River and Marine Connections

The Kimberley forms a large part of the Timor Sea drainage division which receives more than 20 per cent of Australia's total rainfall (National Land and Water Resources Audit 2001). The Kimberley has more than 100 rivers and many more creeks and streams, flowing northward or westward, out from the Timor Sea drainage division.

The sandy plains and river banks in the east and west Kimberley catchments are generally more susceptible to catchment deterioration and soil erosion but the rocky catchments of the North Kimberley are not as prone to these pressures (Holmes 2004). Apart from the Ord and the Fitzroy river basin systems, rivers in much of the Kimberley remain largely unmodified.

Water and water-borne materials are discharged from these drainage catchments to the marine environment. The quantity and quality of these catchment discharges will be affected by natural factors (including climate, topography, geology, soil type, vegetation) and human influences (including human-induced climate change, land use history, soil and vegetation disturbance, river regulation and pollution sources). Broadscale cattle grazing, feral animals, altered fire regimes, irrigated agriculture, dam construction, mining and tourism are factors which can alter catchment hydrology, exacerbate erosion and increase nutrient, sediment and other chemical loads to the marine environment.

Once discharged from the river systems, the loads of sediments, nutrients and other chemicals are transported by currents and waves and have the potential to influence marine water quality, seabed sediments, biodiversity and productivity

over substantial areas. Human influences in the catchments therefore can have potentially significant impacts on the marine environment.

Because of projected constraints on the availability of water in southern Australia and the increased global demand for food commodities, there is increasing pressure to expand irrigated agriculture in northern Australia.

The two most modified catchments in the region are the Ord River and the Fitzroy River catchments. Irrigation dams have been constructed on the Ord, the Dunham River (an Ord tributary) and on the Lower Fitzroy at Camballin.

The Ord River Irrigation Project began in 1963 with the commissioning of the Kununurra Diversion Dam and 12,000 ha of serviced farmland. With the completion of construction of the Ord River Dam and associated irrigation infrastructure in 1972, Stage I of the development was available for irrigation. The government of Western Australia is now progressing with the staged development of Stage 2 of the Ord River irrigation area, which potentially will create an additional 16,000 ha of farmland in Western Australia. Future development of the project in the Northern Territory has the potential to include a further 14,000 ha of farmland (Braimbridge & Malseed 2007).

The Ord River Irrigation Project has led to changed hydrology, altered flows, retention of nutrients and sediments, and the introduction of agricultural chemicals (pesticides) to aquatic systems.

The impact of the Ord River dams on the geomorphology and ecology of the lower Ord estuary has been briefly studied (Wolanski et al 2001; Parslow et al 2003) but requires further evaluation. The lack of baseline data and the relatively short timeframe of monitoring and regulation mean that an accurate assessment of the magnitude of threats to the ecosystem is difficult. The system has yet to reach a stable condition under the regulated flow regime, which makes responses to future changes difficult to predict. This difficulty is compounded by the lack of basic knowledge about much of the system, with no comprehensive ecological studies downstream of the freshwater zone (Gehrke 2007).

The proposed Stage 2 of the Ord River irrigation area was the main driver for research on the lower Ord River and estuary. It was originally proposed to establish a marine research subprogram with a much broader spatial scope, including Cambridge Gulf and the West Arm, and to link this research with existing AIMS research in Cambridge Gulf. That did not prove possible because of limited resources. Still, it is clear that the Ord River estuary is strongly coupled to Cambridge Gulf and the West Arm, and it would be highly desirable to extend the spatial scope to include these systems in future.

The Northern Australia Land and Water Taskforce, established by the Federal government is to consider a broad range of development opportunities related to water use, including tourism, mining and other industry.

The Northern Australia Irrigation Futures (NAIF) project seeks to ensure that irrigation in northern Australia, is planned and managed sustainably within a catchment context. The NAIF project is well linked with NRM regional bodies, local governments and communities across northern Australia, and with the Commonwealth, Western Australian, Northern Territory, and Queensland governments who have responsibilities for tropical Australia.

There is a pressing need for better understanding of terrestrial-marine linkages, the implications of changes in catchment management on the near-shore marine environment, and incorporation of this understanding into integrated planning and decision-making.

The mouths of rivers and creeks provide important habitats for a range of species not found elsewhere in the region. Geomorphic features associated with sediment, such as sand banks, create environments for seagrass to grow and provide habitat for summer breeding birds.

Estuarine and near-shore marine areas are of importance to the Indigenous people, and are popular fishing areas and visitation areas for marine based tourism. Water quality is a critically important parameter for uses such as pearling and aquaculture, which may be sited within the area of influence of

river outflows. Catchment management, therefore, has an important bearing on the marine-based human uses of these areas.

Not all of the required science and information to address the influence of land use and catchment management on the marine environment is within the remit of WAMSI. For instance, quantification of catchment water, sediment and nutrient discharge is an essential input to the marine science. The Tropical Rivers and Coastal Knowledge project (TRaCK) seeks to understand and predict how material budgets (water, sediments, nutrients), aquatic food webs and biodiversity in the river systems would change in response to development and climate change (Land & Water Australia 2007). It is recommended that WAMSI establish close links with (and source the relevant data from) terrestrial programs such as TRaCK, and natural resource management agencies such as the WA Department of Water and the National Land and Water Resources Audit.

Adequate baseline characterisation and ongoing monitoring of marine quality, habitat and ecosystem health indicators, and catchment input data, combined with an understanding of ecological linkages and area of influence of the riverine outflows is required to assess the nature and extent of catchment influences on the marine environment.

There is a need for the science findings about the nature and extent of catchment influences on the marine environment and its users to be very clearly communicated to the relevant decision-makers so that potential marine impacts are factored into catchment management plans and decision-making.

Climate Change

The following material is adapted from a report (Johnson & Marshall 2007) on the vulnerability of the Great Barrier Reef to climate change.

Climate change is unlike any other disturbance: it has the potential to simultaneously and severely affect tropical marine ecosystems spanning hundreds and thousands of kilometres. Changes associated with climate change that are likely to have implications for the Kimberley-Browse marine region include increasing air and sea temperatures, ocean acidification, changed nutrient status, altered light levels, more extreme weather events, changes to ocean circulation and sea level rise.

Projected changes in air temperature are significant for habitats exposed to air, such as mangroves, intertidal seagrass and other coastal habitats. Many of the species in these habitats are also sensitive to changes in air temperature, particularly extremes of temperature (e.g. marine turtles and seabirds).

An increase in sea temperature is likely to be the most critical of all changes to the region's climate, having implications for most marine species. Species groups from corals and plankton to fish and seabirds are sensitive to these changes.

Species and habitats in the intertidal zone are particularly vulnerable to sea level rise, including seagrass, mangroves and associated wetlands, coasts, estuaries, islands and marine reptiles.

While many species groups have intrinsic sensitivities to climate change, there are also groups that will experience indirect effects. These indirect effects result from the linkages and inter-dependencies among organisms, and between organisms and processes. This extensive connectivity, which characterises marine ecosystems, means that impacts on one component of the ecosystem are likely to have flow-on effects for other components.

Changes in circulation will alter patterns of larval transport and hence biological connectivity and fisheries recruitment. Changes in nutrient upwelling onto the continental shelf and changes in catchment runoff will affect the nutrient status and water turbidity, with implications for the distribution of benthic primary producer communities and marine productivity in general.

Changes in the frequency and intensity of extreme events (e.g. cyclone-generated winds, storm surge and ocean waves) will alter sediment mobility, coastal erosion/accretion, inundation of the supratidal zone and will impact biological communities.

From a human use perspective, coastal and offshore infrastructure is potentially at risk of significant damage and increased shut-down periods from increases in storm surge, higher winds, more intense cyclones, flooding and wave events, especially when combined with sea level rise. Damage to ports, shipping and subsea pipelines could also threaten infrastructure performance, security and supply at significant cost to the economy and local communities. Although offshore platforms are designed to withstand extreme conditions, frequent storm periods can disrupt supply and affect the downtime and safety protocols for workers (Allen Consulting Group 2005). Long infrastructure lead times, significant amounts of private and public sector investment, and the long-lived nature of assets call for more explicit consideration of climate change factors in government planning and assessment of infrastructure developments.

The Indian Ocean Climate Initiative (IOCI) is a partnership of the Western Australian Government, CSIRO and the Bureau of Meteorology, which was formed to support informed decision-making on climate variability and change in Western Australia.

IOCI held a workshop entitled 'Living with our Changing Climate' (Dracup, McKellar, & Ryan 2005) which identified the need for:

- more credible projections of future climate at a regional and sub-regional scale, to underpin informed regional responses to climate variability and change;
- improved understanding of interactions between climate and ecosystem composition, structure and function, and how changes in climate might affect ecosystems;
- better baseline information on ecosystem condition and variability for projecting future impacts; and
- better knowledge about potential indirect impacts, such as the invasion and spread of ecological pests and diseases.

IOCI has sought to expand its underpinning science portfolio to include the whole of Western Australia, including its North West, and has identified benefits from strengthening alliances with similar science initiatives in WA, such as WAMSI (Dracup, McKellar, & Ryan 2005).

The IOCI Stage 3 project focuses on the current and projected terrestrial climates of the north west and south west regions of WA, while WAMSI projects focus on oceanic drivers, marine responses and coastal vulnerability to climate change. Complementary outcomes from IOCI Stage 3 and WAMSI projects will provide a more complete understanding of the Western Australian climate and will better inform the development of adaptive management strategies.

The state of scientific knowledge and predictive capacity of climate change in the Kimberley is not well developed. Its effects on the region's meteorology and oceanography are not well understood, and very little is known about the impacts of climate change on its biodiversity and biological systems, the responses (adaptation) of these systems, and management strategies to support ecosystem function and maintenance of biodiversity. Likewise, there is very little known about the ecological susceptibility of the region to the interacting pressures from climate change and other human-induced causes.

government commitments and decisions

Government Commitments

A number of international treaties and conventions, national strategies, inter-governmental agreements and State policies and strategies have been committed to by the different levels of government in Australia. These include:

International treaties and conventions, for example:

- Convention on the Law of the Sea;
- Convention on Biological Diversity;
- Convention on the Protection of the World Cultural and Natural Heritage.

National policies, strategies and inter-governmental agreements, for example:

- National Strategy on Ecologically Sustainable Development;
- National Strategy for the Conservation of Australia's Biological Diversity;
- Australia's Oceans Policy.

State policies and strategies, for example:

- State Sustainability Strategy;
- State Planning Policy 2: Environment and Natural Resources;
- Ecological Sustainable Development for Fisheries & Aquaculture Policy;
- Draft Biodiversity Conservation Strategy.

These various strategies and policies together point toward outcomes that include:

- better understanding of marine ecosystems and their values;
- long-term protection of marine ecosystems and ecological processes;
- maintenance of biological diversity;
- recognition and protection of the traditional knowledge, customs and practices of Indigenous peoples;
- sustainable use of marine resources; and
- sustainable economic, social and environmental futures for the region, state and nation.

Specific commitments for Australia's marine jurisdictions include:

- marine bioregional plans for conservation and use;
- a system of comprehensive, adequate and representative (CAR) marine protected areas;
- ecosystem-based management;
- management to prevent or combat marine pest introductions;
- improved environmental impact prediction and management; and
- understanding climate change impacts and developing responses.

However, the Kimberley-Browse marine ecosystems are *poorly understood,* and this is a significant barrier to implementing these commitments in the region.

Government Decisions

Recognising the importance of maintaining the unique natural and cultural values of the Kimberley, improving the livelihood of its Indigenous peoples and regional communities, while utilising its vast reserves of offshore gas, governments are already preparing to make big policy decisions which will shape the future of the Kimberley-Browse marine region.

Strategic Assessment for an LNG Processing Hub Site

The Commonwealth and Western Australian governments have agreed to a two-phase joint strategic assessment under the Commonwealth Environment Protection and Biodiversity Conservation Act and the WA Environmental Protection Act (Joint Ministerial Press Statement 2008).

The first phase will assess preferred options, identified by the Northern Development Taskforce, for the location of a *Common-User LNG hub precinct* for processing Browse Basin gas. This assessment is scheduled for completion in mid-2009.

It is envisaged that the hub precinct would be able to accommodate LNG trains servicing multiple offshore gas production operations in the Browse Basin. In addition, the hub would be able to contain ancillary infrastructure (such as construction camp, airstrip, tug harbour), storage and export facilities, and other chemical manufacturing industries reliant on natural gas feed. The seaward infrastructure components of such a hub would include export wharves, materials offloading facilities, navigation channels and boat harbours. The objective of the hub is to provide for the needs of industry but to prevent ad hoc proliferation of infrastructure along the Kimberley coast.

The data and information to support the strategic assessment are required in time for the assessment to be finalised in mid-2009, released for public comment, considered by the responsible State and Commonwealth environmental agencies, and a report and recommendations prepared for determination by their respective Ministers. WAMSI, through several of its research member organisations , conducted marine surveys and biodiversity assessments to support the site selection and strategic assessment processes.

Strategic Assessment for Natural Heritage Listing of the Region

The second phase strategic assessment will be a broadscale study to provide a picture of the region's environmental assets including national and international heritage values, and will be carried out in consultation with conservation groups, industry and Indigenous landholders (Joint Ministerial Press Statement 2008).

The marine component of this second phase assessment will focus particularly on state coastal waters off the Kimberley coast. This process is scheduled to commence in July 2008 and will last for approximately two years. This still leaves only limited time to gather new information to feed into the strategic assessment of natural heritage values, since this assessment covers a much broader area than the hub assessment. The WAMSI partners are well positioned to undertake the necessary marine survey work and also to provide expert interpretation of the region's natural values against National Heritage criteria.

Commonwealth Marine Bioregional Plans

The Federal government is developing a series of Marine Bioregional Plans for Australia's Exclusive Economic Zone, not including State coastal waters (Department of the Environment, Water, Heritage and the Arts 2008). These plans are designed to consolidate available knowledge about marine ecosystems and human activities in the regions, and provide an improved basis for decision-making about the conservation of the marine environment. Marine bioregional planning is also the process the Commonwealth government is using to identify new Marine Protected Areas (MPAs) to contribute to Australia's National Representative System of MPAs.

The marine bioregional planning process for the north west of Australia is currently underway (Department of the Environment, Water, Heritage and the Arts 2008). The north west marine plan covers Commonwealth waters from the Western Australian/Northern Territory border to Kalbarri, south of Shark Bay, and encompasses Commonwealth waters of the 'Kimberley-Browse marine region', the subject of this report. A bioregional profile report which draws on available, existing data on the north west is scheduled for completion by mid-2008. That will be followed by the preparation of a draft Marine Regional

Plan which is scheduled for publication in mid-2009. There will then be a period of formal public comment, which is required under the EPBC Act.

Once the Plan is finalised, it will guide future Commonwealth government conservation activities in the region. An implementation strategy for the Plan will be developed and the formal legal processes to declare the MPA network will commence. The Plan will be reviewed from time-to-time in the light of new information and emerging priorities.

The bioregional profile will have served to identify numerous gaps in scientific knowledge and understanding of the bioregion. Filling these gaps will be a priority issue to progress effective implementation of the Plan.

State Regional Marine Planning

Currently there is no multiple-use, regional marine plan applying to state coastal waters off the Kimberley coast. A marine policy stakeholder group is advising the State government on the preparation of a policy framework for regional marine planning (Government of Western Australia 2008). It is envisaged that the policy framework will provide for regional plans to better integrate the activities of the various marine sectors and to achieve protection, maintenance and sustainable use of the marine environment. The strategic plan will be based on the best available science but, at the same time, take into account the views of marine users. Government departments, agencies, maritime industries, non-government organisations, community groups and the general public will all play a role in regional marine planning.

The 'New Horizons in Marine Management' policy, adopted by the State government in 1994, is to be reviewed and updated with input from the policy stakeholder group and a scientific panel to create a new policy on marine conservation reserves for Western Australia.

Implementation of a marine planning strategy for a particular region, such as the Kimberley, would require an assessment by each sector of its performance against ESD criteria.

Ecosystem-based Management

Ecosystem-based management may be defined as dealing with the aggregate management of all sectors (fishing, shipping, tourism, mining, etc.) operating within or affecting a single region to achieve ESD outcomes (Fletcher 2006). The 'competition' among these sectors for allocation of access to the region's resources and the effects of one use upon the environmental requirements of another use must also be dealt with as part of this approach. To be effective, ecosystem-based management requires a process whereby 'whole-of-government' ESD objectives and performance measures for the region can be generated.

As an example of this, the South Australian government is currently implementing a Marine Planning Framework which embodies these features (Government of South Australia 2007), to provide for integrated, and ecologically sustainable use, and to further the protection and conservation of biodiversity and other intrinsic values of the marine environment. A performance assessment system has been developed to determine whether the regional marine plans are meeting their objectives.

Longer-term Perspective

The various government processes and policies mentioned above could provide the stepping stones toward a sustainable future for the Kimberley-Browse marine region. As human use demands in the region continue to grow, and as the effects of climate change continue to intensify, there will be a continued requirement for updated information to service ongoing management and decision-making. In this uniquely twenty first century situation, managers will be looking beyond traditional approaches and will be evaluating the relative ecological and socioeconomic merits of alternative, new management strategies. As never before, these decisions will rely critically on good quality information. In this context, it is of paramount importance and urgency to establish and build up baseline and long-term data sets in relation to human use and climate change pressures, the

response of the natural systems to these combined pressures, and related social implications. The priority strategic science areas outlined in this report can play a key role in shaping plans and cost-effective monitoring and management systems for the region.

existing science and science gaps

Before outlining the strategic science requirements for the Kimberley-Browse marine region and the proposed pathways for implementation, a brief summary will be given here of relevant past research conducted in the region and critical gaps in science will be assessed.

Existing Science

In the past couple of years there have been several reviews of research and knowledge concerning the natural values, ecosystems and human uses of Kimberley near-shore and offshore marine areas (Fletcher & Head 2006; Brewer et al 2007; Department of the Environment and Water Resources 2007; Inpex Browse Ltd 2007; Marine Coastal Community Network 2008; Mustoe & Edmunds 2008; Woodside Energy, 2008). While referring to the existing science, these reports also highlight the many fundamental gaps in our knowledge of this region.

Oceanography and Geophysics

Research on the Indonesian Throughflow and the south east Indian Ocean is developing the broadscale oceanographic context for the region. However, ocean circulation within the region itself is still not well-defined and the extent and frequency of nutrient upwelling onto the continental shelf is poorly understood.

Drifter trajectories and model experiments have been used to investigate water circulation and connectivity within and between outer-shelf atolls, but cross-shelf and near-shore circulation and connectivity also need to be addressed to gain a broader understanding of genetic dispersal processes connecting communities through pelagic larval phases.

Tidal currents are found to dominate on the broad continental shelf and these have been shown to be important agents of sediment mobilisation and vertical mixing, particularly in shallower areas and in the wake of islands.

Regional and shelf-scale hydrodynamic models have been developed but there are relatively few locations where current meter data are available for use in assessing the performance of these models. Some of the models do not incorporate the tides and tidal currents. The models generally do not have fine enough grids to resolve the complex bathymetries found near islands or coastal embayments.

Most current meter and other meteorological and oceanographic data are from areas of interest to the oil and gas industry. These data have mainly been collected near the outer edge of the shelf under non cyclonic and cyclonic conditions for engineering design purposes. They have been used to study the generation of internal waves which give rise to rapid currents and need to be considered in the design of offshore structures. Several current meters were recently deployed at inner shelf locations in areas under consideration for a multi-user LNG hub.

Geoscience Australia has conducted broadscale seabed characterisation over the shelf and slope. This information is useful for engineering design purposes and also has enormous potential to provide broadscale 'surrogate' information on the likely distribution of habitats and their biological communities.

The near-shore hydrodynamics and sediment regimes of Cambridge Gulf and King Sound have received attention. The Cambridge Gulf investigation made an assessment of the effects of dam construction on estuarine and near-shore marine processes. In most other near-shore localities very little work has been done.

From a regional perspective there is still a paucity of meteorological, oceanographic and fine resolution bathymetry data, and a need to improve the understanding and prediction of physical processes which are important drivers for the ecology of the region.

Biology and Ecology

Much of the biological and ecological research within the region has been focused upon the offshore reefs and islands of Ashmore, Cartier, Scott, Seringapatam and the Rowley Shoals. AIMS has been monitoring fish and coral communities on Scott Reef since 1994, to understand their natural variability. Detailed work has also occurred around the Maret Islands. The above-mentioned locations are either declared marine protected areas or areas of interest for the production and processing of petroleum and natural gas.

The WA Museum, WA Universities and others have conducted surveys and biodiversity assessments of the intertidal and near-shore, subtidal communities at selected localities along the Kimberley coast.

Extensive seagrass habitats, structurally complex and diverse fringing coral reefs and filter feeding communities have been observed in particular inshore areas. Recent detailed surveys of intertidal and shallow subtidal habitats and benthic communities were conducted in the vicinity of locations being considered for a LNG hub. However, apart from a few specific areas, these communities have not been mapped elsewhere in the region. Their biodiversity, environmental requirements, ecological linkages and resilience to stress are all poorly understood.

Humpback whale surveys have been conducted in the Kimberley, with the aim of identifying migration patterns, populations, groups and critical areas used as calving grounds. This work has been supported by industry, government, universities and private research organisations. Work on marine turtles in the Kimberley has been more limited, and even less is known about the populations, life cycles and environmental requirements of dugong.

Much remains to be done to arrive at a systematic understanding of the natural values and assets, their variability and environmental requirements at regional, shelf and local scales.

Human Use

An understanding of the type, distribution and intensity of human use in the region, and projections of future trends is an essential input to the assessment of the social values associated with the marine environment, the anthropogenic pressures exerted on marine ecosystems and allocating priorities for issue-based marine research.

A review of major human uses in the region has been provided earlier in this report.

The Kimberley Development Commission and the WA Department of Local Government and Regional Development publishes an annual Kimberley Economic Perspective report which provides a summary of the latest available information on population, labour force and employment, mining, agriculture, fishing, manufacturing, construction, commerce, tourism, Indigenous economic development and infrastructure. This report collates information from the Australian Bureau of Statistics and a range of Commonwealth, State and local government agencies as well as from private sector organisations.

As part of its Marine Bioregional Planning program, the Federal government compiles human use data and atlases on fisheries and non-fisheries uses in Australia's marine jurisdiction. The current focus of this program is on the North West region, including the Kimberley-Browse marine region.

Indigenous Knowledge

In the past and through to the present, Indigenous Australians have drawn on a sophisticated understanding of human/environmental relationships in order to successfully manage their vast land and sea estates. This understanding is now, in some cases, seriously threatened. The North Australian Indigenous Land and Sea Management Alliance (NAILSMA) was established by the peak Indigenous natural resource agencies across northern Australia taking in the Kimberley, the top end of the Northern Territory, and the Gulf of Carpentaria and Cape York. Goals and objectives for marine and coastal management programs have been developed by NAILSMA in collaboration with partner organisations such as the Kimberley Land Council (KLC) and the CRC for Tropical Savannas (NAILSMA 2006).

Smyth (2007) has compiled a significant review of Indigenous knowledge of north west Australia. Other initiatives such as Tropical Rivers and Coastal Knowledge (Land and Water Australia 2007) are drawing on Indigenous knowledge to enhance understanding and management of tropical rivers and estuaries across Australia's north, including the Kimberley. Government agencies are seeking practical ways of incorporating Indigenous aspirations into natural resource management. For example, a draft Aboriginal Fishing Strategy (Department of Fisheries 2003) has been prepared to examine how fisheries management can include and recognise Indigenous people's use of fish for food, cultural reasons and for economic development.

Science Gaps

The marine ecosystems of the Kimberley are amongst the least studied of any on the west and north west coasts of Australia (Department of the Environment and Water Resources 2007). Very little is known about the inshore marine areas of the Kimberley, generally the best understood areas of other systems, as well as areas further offshore.

Broadscale Climate and Oceanography

The climate and oceanography of the south east Indian Ocean are only partially characterised, and their influence on the Kimberley's oceanography, biology and ecology is poorly understood. More research is required to understand how currents transport waters from the Indonesian Throughflow (ITF) through the Kimberley marine system, and what effect the north west monsoon has upon these systems (Brewer et al 2007).

There is insufficient information on the spatial and temporal variability of these broadscale meteorological and oceanographic features. The transport of genetic material from Indonesia to the waters of WA is not well understood, and little is known of the role of the ITF and SE Indian ocean gyres and the ocean's temperature/density structure in moderating nutrient upwelling and productivity on the shelf. Knowledge of the variability in the oceanic temperature/density structure is critical for predicting the locations and timings of internal wave generation near the outer shelf (Stroud & Steedman 2002).

Much more research is required to understand and predict the coupled ocean-atmosphere system, particularly its regional response off north west Australia to global climate change (Dracup, McKellar, & Ryan 2005). Little is known of the seasonality, inter-annual to decadal variability and longer term changes in the meteorological and oceanographic forcings, and how these changes will affect the ecology and human uses of the region. Region-specific changes in parameters such as marine water temperature and acidity, sea level, cyclone intensity, rainfall and catchment hydrology will be important agents driving marine ecosystem responses to climate change (Johnson & Marshall 2007). Currently there are only preliminary estimations of their likely change.

Slope, Shelf and Coastal Processes

Oceanographic data on the Kimberley Shelf are found primarily in locations of interest to the offshore oil and gas industry, and there are very few measurements elsewhere (Godfrey & Mansbridge 2000; Cresswell & Badcock 2000; Andrewartha et al 2006); this is particularly the case for inner shelf and near coastal areas. WAMSI has recently coordinated the deployment of current meters and tide gauges in the vicinity of potential sites for a proposed common user LNG processing hub. These data are critical for site selection, environmental assessment and engineering design of the hub. Further data will be required elsewhere in the region to support National and World Heritage values assessments, coastal vulnerability assessments, integrity of infrastructure (e.g. subsea pipelines) and planning for human uses such as pearling and aquaculture. The development of a spatially nested set of models capable of reliably predicting (at both regional and local scales) water circulation, tidal currents, sediment mobility, dispersion of river outflows, effluent dispersion will be an extremely valuable strategic tool with multiple applications.

There is a critical need to improve characterisation and predictive capability in relation to extreme events. Strong currents and seabed scouring associated with internal waves and tropical cyclones must be factored into design/risk calculations and operational contingency plans for offshore infrastructure such as oil and gas platforms and pipelines. The magnitude of internal wave currents is a function of the thermocline characteristics, local seabed slope and the tidal forcing (Stroud & Steedman 2002). Similarly, cyclone induced storm surge, extreme wave conditions and tidal currents need to be accurately characterised and factored into the design of coastal infrastructure, port operations and oil spill response plans.

There is inadequate knowledge of continental shelf and near-shore circulation patterns and processes. This is required to predict dispersal pathways for materials such as nutrients, fish larvae and oil spills, the distribution of habitat types, biodiversity and endemism, and is an important factor determining the suitability of sites for marine-based operations such as pearling and aquaculture.

Ecological research within the region has largely been focussed upon the offshore reefs and islands of Ashmore, Cartier, Scott, Seringapatam and Rowley Shoals, and in the vicinity of the Maret islands. Consequently, scientists have a reasonable knowledge of their biodiversity but, even in these areas, ecosystem processes are only partially understood (Department of the Environment and Water Resources 2007).

The reproductive patterns (e.g. spawning areas, migrations and timing) of most key species (both migratory and site attached species) are poorly understood, as are the likely dispersal pathways for their larvae, and hence the potential ecological importance of various subregions to neighbouring sub-regions is not known (Brewer et al 2007).

The drivers and mechanisms of biological productivity on the continental shelf (and slope), and the way in which they govern its seasonal and inter-annual variability, as well as the spatial distribution of production regimes, still remain largely unknown (Brewer et al 2007).

Key information gaps exist on the mechanisms and variability of nutrient delivery to (and cycling on) the Kimberley shelf (Thompson, P. pers comm 2008). The occurrence of nutrient upwelling at the shelf break, vertical mixing (by internal waves, tropical cyclones and tides) of nutrients into the photic zone, benthic-pelagic coupling and riverine inputs are all nutrient supply mechanisms which can potentially enhance productivity, but they are not well understood. The role of atmospheric nitrogen fixation as part of biogeochemical cycling in this region needs to be determined.

Little is known about the spatial and temporal variability of the photic zone, or of the bottom light regime. Near-shore and inner shelf areas are expected to experience highly variable levels of turbidity, due to a combination of tidally-induced sediment re-suspension and riverine sediment discharge. Bottom light regimes may be an important factor in determining the zonation of benthic primary producer communities. Freshwater discharge, strong tidal currents and depth gradients are likely to generate seawater density fronts and resultant accumulations of surface residing materials (e.g. phytoplankton). All of these processes will influence the distribution and level of productivity on the shelf.

Little is known of the ecological processes, food webs and linkages supporting communities (all trophic levels) and structuring ecosystems of the shelf and inshore, shallower, turbid zone. The same can be said of the offshore continental slope and deeper areas (Brewer et al 2007). This information will be required for conservation planning and ecosystem-based fisheries management.

Biological Resource and Human Use Inventories

There are major scientific data gaps in regard to marine fauna and flora in the region, with many species not yet identified and ecological communities not yet described or mapped (Holmes 2004).

The use of geomorphology and sediment properties as physical surrogates for benthic biological communities is regarded as a cost-

effective way to provide a greater understanding of marine ecosystems and their biological resource distributions (Bax & Williams 2001; Post, Wassenburg, & Passlow 2006).

A higher sediment sample density is required to more accurately map the spatial distribution of sediment properties (and by association benthic biota) on the inner shelf, in submarine canyons and the abyssal plain/deep ocean floor of the Kimberley-Browse marine region (Potter et al 2008). Within State coastal waters of the region marine sediment data appear to be extremely sparse, with the exception of the Cambridge Gulf/ Joseph Bonaparte Gulf area (Potter, A. pers comm 2008). It is important to increase the sediment sample densities, particularly in areas of the seabed that are likely to contain significant variations in sediment characteristics over relatively small distances.

Extensive seagrass habitats, structurally complex and diverse fringing coral reefs and filter feeding communities have been observed in various shallow subtidal areas. By and large, they have not been mapped and their biodiversity, environmental requirements, ecological linkages and resilience to stress are all poorly understood (Masini, R. pers comm 2008). However, in June 2008, WAMSI has facilitated coordinated marine benthic surveys of approximately 800 km^2 in total at four inshore Kimberley locations identified as potential sites for a proposed common user LNG processing hub, to provide essential data for input to the site selection process.

The shallower coastal zone is poorly understood but may support significant populations of filter feeding invertebrates such as sponges and bivalves, and scavengers such as crabs, shrimps and bottom dwelling sharks and fish. There is likely to be an abundant demersal community dominated by primary and secondary consumers. However, little is known of their species composition in this zone (Brewer et al 2007).

The benthic invertebrate species forming key habitats on the channels, banks, islands and shoals of the shelf are not described, nor are the benthic communities of the less structured midshelf regions between the key habitats (Brewer et al 2007). The impacts of the trap and line fishery on channel and bank trophic systems is poorly understood.

Little is known of the habitats and composition of offshore pelagic and benthic communities, in the abyss and slope (beyond shelf break) predominantly due to the difficulty and cost of research in these waters. The trophic dynamics of all demersal slope communities and the continental slope off north west WA is recognised as a high priority for future research (Last et al 2005).

For north and north west Australia the most recently published work on phytoplankton ecology is the community composition survey in the early 1980s (Hallegraeff & Jeffrey 1984), but with only one or two samples from the Kimberley (Thompson, P. pers comm 2008).

Information on current and potential future activities is important for marine and coastal planning along the Kimberley coast. Activities to be considered need to include Indigenous use, private visitors, commercial tourism activities as well as those resulting from other industries operating in the area (Scherrer, Smith, & Dowling 2008). There is a need to consider both existing and proposed transport infrastructure (e.g. ports, anchorages, roads, airstrips) which provide access to the coast as these open up cultural, recreational and commercial opportunities, but also lead to pressures on the marine environment and resources, which need to be carefully managed.

The recent excellent bibliographic study *Sea Countries of the North west* (Smyth 2007) refers to significant Indigenous knowledge of the region. It also contains important recommendations for the involvement of Indigenous people in fishing, fishing management and economic development of the sea countries.

There is a need for periodic surveys of community aspirations and attitudes (what people value, environmentally, socially and economically), as this should factor into objective setting for regional planning.

Baselines, Natural Variability and Long-term Change

Targeted monitoring provides ongoing information about interactions between the natural system and human usage. Monitoring trends in key indicators (i.e. performance measures) to assess changes in the natural system, human uses and pressures is an essential information component for management. Monitoring provides an assessment of the effectiveness of management in meeting objectives by providing the basis for status reports against management targets, detecting undesirable trends and, if necessary, providing the trigger for remedial action (Simpson, Colman, & Hill 2002).

Surveillance monitoring programs are generally broadscale, ongoing, and are used by management agencies to provide regular (e.g. annual) overall status reports on the health of natural systems, to detect unanticipated change, improve understanding and prediction methods, and to manage adaptively. Surveillance monitoring programs also provide the broader spatial context necessary to interpret the results of local-scale compliance monitoring programs.

Compliance monitoring programs are used to assess industry compliance (or otherwise) with agreed environmental management targets for specific approved activities. Without the broader context provided by surveillance monitoring it is sometimes difficult to interpret the results of local compliance monitoring and this leads to a precautionary approach by regulators.

Apart from some meteorological and tidal stations, there have been very few time-series monitoring programs in the region which have lasted for more than a few years. Satellite data sets, including sea surface altimetry, sea surface temperature and multispectral ocean colour now span one or more decades, however the use of altimetry data over the continental shelf remains problematical in the absence of highly accurate tidal data (Volkov, Larnicol, & Dorandeu 2007), and ocean colour data sets (to estimate chlorophyll a concentrations) require 'ground truthing' and careful calibration, particularly in shallow, more turbid waters. Only when these issues have been addressed, will the satellite data realise its full utility over the continental shelf and inshore areas of the region.

Sustained biological and geochemical time-series data for the region are generally even scarcer than the physical time-series data. One of the very few exceptions to this is on Scott Reef, 300 km offshore, where AIMS has been monitoring fish and coral communities since 1994 to understand their natural variability. AIMS decadal observations provided crucial information in 2007 when the offshore oil and gas industry were granted conditional approval to conduct seismic surveys of the Browse Basin gas reservoirs below Scott Reef (Australian Institute of Marine Science 2007).

As noted above, the seasonal, inter-annual and spatial distribution of marine biological productivity regimes still remain largely unknown. Little is known about the spatial and temporal variability of the photic zone, or of the bottom light regime which drives benthic primary production.

There is an urgent need to establish integrated and sustained monitoring programs at a network of reference locations (not significantly influenced by local human uses) to establish regional baselines, characterise natural variability and provide the foundation for assessing long term change. The program would include monitoring the temporal and spatial variability of key meteorological and oceanographic forcings, ocean structure, sediment mobility, water quality, and the condition of biological communities.

As a baseline for the assessment and evaluation of potential impacts due to human activities in the region, it is fundamental to also invest in the measurement of specific areas which are likely to be (or may already have been) impacted. These environmental baselines should be coupled with a socioeconomic assessment, in order to quantify both the benefits derived from and the impacts resulting from activities in these areas. Until such a baseline is established, coupled with longer term monitoring programs of the area, and with periodic review, management decisions should be based on the precautionary principle (Scherrer, Smith, & Dowling 2008).

Threatening Processes and Ecosystem Response

There are far greater gaps in knowledge of tropical marine communities, their response to stress, and indicators of their health condition than is the case for temperate marine communities (Environmental Protection Authority 2008). There is currently inadequate information available to set many marine resource condition targets for the region (Holmes 2004).

There is a need to develop understanding of key cause-effect pathways linking human pressures, environmental change and potential ecological harm. Improved understanding of these pathways enables managers to correctly identify indicators of emerging problems and to trigger targeted preventative or remedial management actions.

The development of reliable indicators for monitoring ecosystem health condition should include early warning indicators of environmental change that, if left unchecked, could adversely affect valued biological communities, and direct indicators of the health condition of the valued biological communities themselves. There is a need to develop practical, standard methods for measuring and reporting these indicators, for use in surveillance and compliance monitoring programs, so that monitoring by different groups will produce compatible data which can be aggregated. This will provide for a much more strategic, integrated, cost-effective monitoring strategy for the region, and one which has far greater utility for all environmental managers, whether in government, industry or the community.

These investigations should focus on the sensitivity and resilience of communities to stress, and also on their potential to recover from damage. Some of these studies will involve manipulative experiments (e.g. imposing different sedimentation loads to test the tolerance of coral communities), others will be conducted along environmental gradients (e.g. bottom light gradients), while others may study the extent and rate of recovery of particular communities post-impact (e.g. from natural events such as cyclones and coral bleaching, or human activities such as fishing).

Broadly, much more research is required to understand ecosystem structure and function, and the processes which confer ecosystem resilience to stress. Stresses on marine ecosystems, including those associated with climate change (e.g. ocean temperature, acidification), and the responses of these systems to stress need to be understood to inform the development of adaptive management strategies.

These types of studies also depend on a good understanding of the distribution of key biological communities, their limiting environmental conditions, their natural variability and sustaining processes. Hence, they are strongly dependent on characterisations of the structure, function and variability of the environment.

Knowledge of ecological and trophic linkages provides critical information for managers. For example, if subtidal filter feeding communities are found to be sustained by export of biological production from intertidal flats, then managers must view any proposal that would adversely impact on that intertidal production as also potentially impacting on the subtidal filter feeding communities.

The design and evaluation of marine protected areas and fish habitat protection areas will require a synthesis of information. For example, an appreciation of the connectivity of communities through pelagic larval phases (e.g. Andrewartha et al 2006) requires an understanding of the linkage between water circulation regimes, seasonal reproductive activity, and recruitment dynamics (e.g. Rothlisberg & Church 1994).

Integrated Modelling

An integrated modelling approach is required to represent in a consistent manner the many linkages that are important in natural systems. These linkages occur between broadscale and finer scale physical processes, and between the physical, biogeochemical and ecological processes.

Scenario Assessment and Management Strategy Evaluation

Planners, managers, end-users and the community can be helped to explore and consider the relative risks and implications of alternative management strategies and future scenarios prior to making decisions.

Regional scenarios need to be generated in a structured way, with assumptions and levels of uncertainty made explicit. This work needs to build on similar research that has been conducted on the North West Shelf and Ningaloo Reef areas. It needs to bring together the results of research on ecosystems (or key ecosystem processes), human use interactions, climate change, adaptive management strategies and monitoring approaches, particularly as they apply to the Kimberley-Browse marine region.

science for decisions

As demonstrated in this report, the Kimberley-Browse marine region is of national and international significance; it faces unprecedented growth and change in the years to come and, for much of the region, there is very limited understanding of its natural values and their resilience to change.

Vision

The vision driving the marine science case is that, by 2018 ...

> *Planning, conservation, sustainable management and utilisation of the Kimberley's unique marine endowment are underpinned by an adequate understanding of the region's natural, cultural and socioeconomic values and systems.*

Objectives

The primary objective of the WAMSI proposal is to provide the marine science basis for planning and sustainable, integrated management in the Kimberley-Browse marine region for the benefit of present and future generations of Australians.

More specifically, the strategic objectives are to:

1. achieve a better understanding of:
    - the region's marine values, ecosystems, drivers and processes;
    - the opportunities, constraints and implications of human uses of the marine environment;
    - land-sea interactions (coastal vulnerability and catchment-marine linkages); and
    - climate change and its impacts on the marine environment and human uses in the region.
2. interpret and transfer these understandings to support government, private sector and community decision-making for:
    - marine regional planning;
    - maintenance of marine ecosystem integrity, biodiversity, cultural and heritage values;
    - sustainable management of multiple uses;
    - productive marine industries and innovative marine technologies; and
    - prediction of regional climate change impacts on marine ecosystems and human uses, risk assessments and development of adaptive management strategies..

Close working relationships with key government agencies, the private sector and community organisations will be key elements in achieving these objectives.

Scoping Decision Needs and Information Requirements

Imminent government decisions (Table 1), ongoing environmental planning and management requirements (Table 2), and community and industry needs (Tables 3 and 4) have been considered in determining the scope of the proposed marine science program. The philosophy of the WAMSI marine science proposal is to provide timely input in response to decision-making needs, while steadily building up a strategic marine science foundation and science-based management tools to maintain currency of data sets and relevance to emerging issues and needs.

Imminent Government Decisions

These are recent State and Commonwealth government initiatives for the Kimberley-Browse marine region which require initial marine science and human use data inputs within the period 2008-2010.

Table 1: Recent initiatives and imminent decisions of State and Commonwealth governments

GOVERNMENT INITIATIVES & IMMINENT DECISIONS	DECISION MAKER
Common user LNG processing hub (Browse Basin gas)	
• Strategic assessment of preferred hub location;	WA & Cwlth
• Environmental impact assessment for hub infrastructure (e.g. port, dredging, pipelines) and associated industry development proposals;	WA
• Environmental management system for hub precinct.	WA
Offshore oil and gas development proposals (Browse Basin)	WA & Cwlth
• Environmental impact assessment;	
• Environmental management conditions.	
National Heritage Listing and potential World Heritage Listing	WA & Cwlth
• Strategic assessment (marine component –state coastal waters).	
North West Marine Bioregional Plan (Commonwealth waters)	WA & Cwlth
• Marine protected areas.	
Baseline data for monitoring marine impacts of future developments	WA
• e.g. Ord Stage 2; potential Fitzroy Valley agricultural expansion, etc.	

Planning and Management Requirements

Environmental

Maintenance of marine biodiversity, ecological integrity and natural heritage values are fundamental priorities for sustainability of the Kimberley-Browse marine region. They also form the basis for many of the region's social and economic activities.

Planning and management requirements to meet these priorities are listed in Table 2. They call for a sound knowledge and understanding of the region's marine ecosystems, the pressures that may be imposed on them (either now or in the future) and their resilience to these pressures.

Social

The marine and coastal environments of the region are of enormous significance to its social values. They are important for the maintenance of Indigenous culture and traditions, access to land and sea countries, and improvement of community livelihoods. They are also central to public recreational values and opportunities.

Planning and management requirements to meet these priorities are listed in Table 3. Knowledge of the region's current and projected human uses, including their resource and environmental requirements, their interactions with each other, and their potential impacts on the environment, is essential to good planning and management for social sustainability.

Economic

Economic considerations include the establishment and operation of marine-based industries, coastal infrastructure, defence/surveillance capability, and catchment land uses (e.g. urban, pastoral grazing, irrigated agriculture) which may influence the coastal and marine environments.

The WAMSI marine science program will inform regional policies, plans and strategies in a way that provides for industries and commercial enterprises greater certainty that project planning and operational performance is consistent with government strategies for the region.

Table 2. Environmental planning and management issues requiring strategic marine science inputs

ENVIRONMENTAL PRIORITIES	PLANNING & MANAGEMENT ISSUES
Conservation of marine biodiversity	• Regional marine planning • Development of a CAR* system of marine protected areas • Marine protected area management plans • Threatened marine fauna (e.g. turtle, dugong) recovery management plans
Maintenance of ecosystem integrity	• Prevention/management of introduced marine pests • Marine environmental impact assessment • Marine environmental policies (e.g. habitat/environmental quality protection) • Catchment and coastal management plans • Ecosystem-based fisheries management • Pearling and aquaculture management plans
Protection of natural heritage	• State of environment reporting • Assessment of region for World/National Heritage Listing

* Comprehensive, adequate and representative (ANZECC TFMPA 1998)

The proposed marine science program will provide a broader environmental and ecological context (both in space and time) within which data, gathered by industry for environmental impact assessment and monitoring purposes, can be considered. This will lead to improved environmental impact prediction and assessment both from a local and regional perspective, and will also assist industry in the design, implementation and interpretation of environmental monitoring and management programs.

The WAMSI marine science program will generate oceanographic, geophysical and environmental data, knowledge and predictive tools that will directly assist site selection, routing and configuration of infrastructure (e.g. petroleum platforms, gas pipelines), structural design and operations management. This will help to minimise project environmental footprints, reduce environmental risk and increase operational safety, efficiency and productivity.

Furthermore, the continuity of strategic marine science effort that is proposed as a feature of this program will result in ongoing relevance to the robust evaluation and possible implementation of new technologies in the region in response to emerging issues, for example:

- harnessing renewable energy (e.g. tidal power) or sequestration of carbon are likely to be considered as concern for world energy supply and the impacts of climate change continue to mount;
- new forms of mariculture, aquaculture and irrigated agriculture production in the region may be proposed as a consequence of world food security concerns; and
- in relation to human health, marine biodiscoveries leading to pharmaceutical (and other useful) products is considered to have high potential in the Kimberley-Browse marine region.

In many respects the future is unclear and there is an urgent need to establish a broad science base to help manage the environmental, social and economic uncertainties in the region as the future unfolds.

Planning and management requirements to address the economic priorities are listed in Table 4.

Table 3. Social planning and management issues requiring strategic marine science inputs

SOCIAL PRIORITIES	PLANNING & MANAGEMENT ISSUES
Maintenance of Indigenous values Caring for land and sea countries Community livelihoods Marine-based recreation (e.g. diving, boating, fishing, recreation, visual amenity)	• Regional marine planning • Coastal planning • Indigenous harvesting of marine resources • Aboriginal fishing strategy • Natural resource management • Regional, area and local land use plans • Tourism planning • Integrated fisheries management • Assessment for World/National Heritage Listing

Table 4. Economic planning and management issues requiring strategic marine science inputs

ECONOMIC PRIORITIES	PLANNING & MANAGEMENT ISSUE
Marine-based industries (e.g. petroleum and gas, shipping, fishing, pearling, aquaculture, tourism) Coastal infrastructure (e.g. ports, coastal industry, coastal settlements, access) Land Use–Marine Connections (e.g. urban, pastoral grazing, irrigated agriculture, river regulation) Defence / Surveillance (e.g. infrastructure, operations)	Policy frameworks which provides greater certainty for industry and community • Regional marine policies and plans • Coastal planning • Regional, area and local land use plans Safe, efficient operations which do not compromise environmental and social values • Environmental and socioeconomic characterisation of the region • Assessment of alternative sites and site selection • Infrastructure design • Environmental impact prediction, management and contingency plans • Approvals processes and regulation • Risk management, safety and emergency response • Monitoring, performance assessment and management review

Climate Change Impacts – Prediction and Management Responses

The issue of climate change has the potential to impact on all aspects of regional sustainability – environmental, social and economic – through its effects on the meteorology, oceanography and ecosystems of the region, and the human uses of its coastal and marine areas. It is therefore of critical importance that the WAMSI science program contributes to an improved understanding and predictive capability of climate change and its implications in the Kimberley, as a basis for better planning and adaptive management strategies.

The IOCI Stage 3 project focuses on the current and projected terrestrial climates of the north west and south west regions of WA, while WAMSI projects focus on changes in climate as they affect marine ecosystems, marine-based industry and coastal vulnerability. Complementary outcomes from IOCI Stage 3 and WAMSI projects will provide a more complete understanding of the Western Australian climate and will better inform the development of adaptive management strategies.

Integrated Marine Planning

Current management responsibilities are established under different Commonwealth, State or local government legislation for various matters including conservation of natural and cultural heritage values, conservation of flora and fauna, maintenance of biodiversity, marine protected areas and marine conservation reserves, fisheries and fish habitat management, land use planning, ports, industrial and resource development, and tourism. These management arrangements are administered by different agencies from the various levels of government.

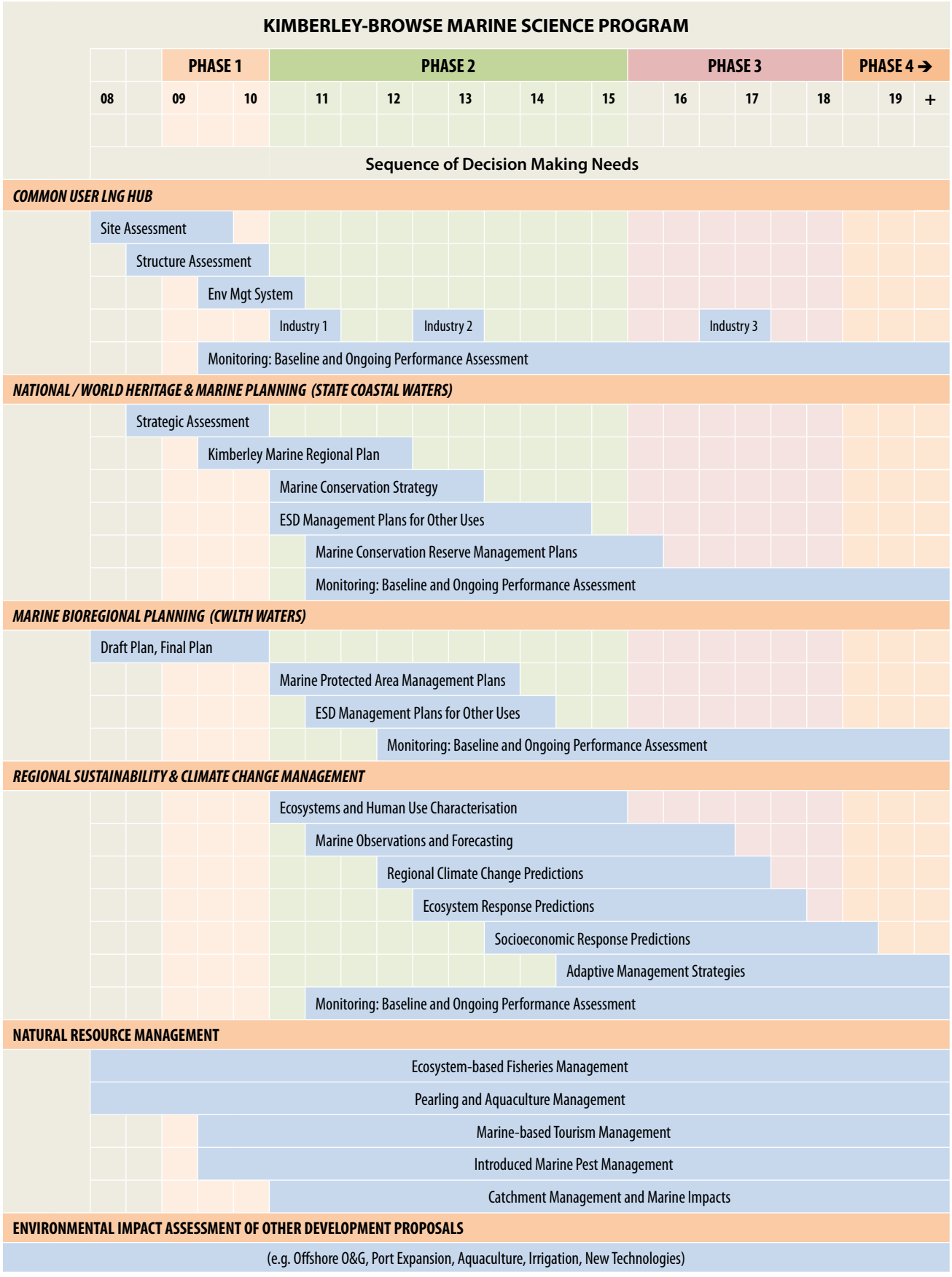
The absence of an overarching marine plan and authority to coordinate these management functions, and the limited resources that each agency is able to deploy in the region, presents an impediment to progress toward regional sustainability. This lack of management coordination probably explains the relatively low level of past investments in understanding marine processes and documenting fundamental baseline information at an ecosystem level or regional scale.

Sustainable, integrated marine planning and management systems are required for the region. They provide the strategic framework within which sectoral and individual decisions and investments are made. Planning and management systems are critically dependent on a solid scientific foundation, incorporating baseline data, knowledge of values and assets, understanding of pressures and threats, predictive capacity and ongoing monitoring against performance indicators leading to adaptive, evidence-based management.

Ongoing Need for Science

Table 5 shows several of the major regional priorities and lists other 'flow on' processes and decisions associated with each of them. The Table demonstrates that, for the foreseeable future, decision-makers, end-users and the community will require a wide range of science inputs to address these priorities, inform decisions and service the needs. It will be essential to maintain currency in data sets and contemporary relevance of science-based management understanding to keep abreast of increasing pressures, emerging challenges and new opportunities in the region.

Table 5: Timing of the marine science program phases to address major regional priorities and decision needs



a proposal for strategic science

The proposed program has four strategic science themes encompassing seven interacting research areas where results will be required to attain regional priorities. The WAMSI program will build on what is known, integrate knowledge and inform stakeholders and decision-makers in a timely manner. The program will generate knowledge applicable for multiple purposes (see Tables 1 to 5). The data, information and products created by this program will be archived and managed by professionals, maintained in perpetuity and made readily accessible as a public good for use by all parties.

Table 6 details the four strategic science themes and seven associated research areas about which research teams could be formed. Theme 5 is for a data acquisition and information management system that enhances all four of the strategic science themes and provides ongoing operational services to managers and stakeholders in the region.

A brief description of these research areas and their relevance to planning, management and decision-making is set out in Table 7 and they are discussed in greater detail from page 43 onwards.

Table 6: Strategic science themes and their associated research areas

STRATEGIC SCIENCE THEMES	RESEARCH AREAS
Theme 1: Values and Assets	• Marine resource and human use inventories • Baseline, natural variability and long-term change in marine ecosystems and their drivers
Theme 2: Sustaining Processes	• Broadscale climate and ocean processes • Continental slope, shelf and coastal processes • Integrated physical, biogeochemical and ecological modelling
Theme 3: Threatening Processes	• Cause-effect pathways, impact prediction and early warning
Theme 4: Scenario Assessments and Management Strategy Evaluation	• Planning tools for ecologically sustainable development
DATA ACQUISITION, MANAGEMENT AND DELIVERY THEME	
Theme 5: Marine Monitoring Network and Performance Assessment System	• Data acquisition, management and delivery system • Maintaining currency of marine data to ensure continued relevance and effectiveness • Integrating data streams in near real time

The coordination and delivery of data, knowledge and understanding from these research areas will need to be carefully programmed and tailored to provide timely inputs to priority decision-making processes. For this reason research and delivery of results will occur in each of four phases (see Table 5) which are scheduled to match with current and future planning and decision needs in the region.

The first phase will begin immediately and end in mid-2010. As a priority it will deliver marine survey information (including baseline habitat mapping, biodiversity assessments and oceanographic observations) in areas targeted for government decisions and at suitable reference locations. This work will also provide a basis to support planning for research work to be conducted during the subsequent phases.

The second phase will build on the first and end in 2015. It will characterise the natural values and dynamics of the region, including significant interactions between its ecosystems and human uses. This information is required for marine regional planning, management of marine biodiversity and ecosystem integrity, Indigenous values, sectoral ESD assessments, coastal infrastructure, environmental monitoring and response to climate change.

The third phase will run to mid-2018, building on phase 2. It will investigate critical cause-effect pathways between pressures (either from natural events, human uses or climate change) and marine ecosystems, provide understanding of ecosystem resilience to stress, develop impact prediction models, and monitoring strategies, develop models of socioeconomic response to change, and generate future scenarios to feed into planning processes.

The fourth phase will focus on implementation, evaluation, review and adaptation. This includes performance assessment against regional sustainability objectives and will require ongoing monitoring to maintain the currency and relevance of the science to planning and adaptive management into the future. This phase will also see improved meteorological, ocean and long-term climate forecasts; reassessments of future regional scenarios and further evaluation of management strategies to address cumulative pressures experienced in the region.

In each phase, there will be a focus on the provision and use of scientific knowledge for decision-making at local, sub regional or regional scale.

Table 8 illustrates that the relative emphasis between the four strategic science themes (Themes 1 to 4) will vary between the phases, shifting from description and characterisation of environments and human uses, to functional understanding of natural systems, ability to predict their response to human use and climate change, and ultimately to assessments of future scenarios, cumulative impacts and management strategies.

Table 7: Research areas and their relevance to regional planning, management and sustainability

1. Broadscale climate and oceanography

To enhance understanding of climate and oceanography of the south east Indian Ocean and their role in driving physical and biogeochemical processes in the embedded Kimberley-Browse region. This will lead to benefits in greater understanding and prediction of:

- regional climate variability and long-term trends (e.g. cyclone frequency, rainfall, sea level, ocean temperature)
- the connectedness with other regions as a factor controlling/sustaining biodiversity
- fisheries recruitment processes
- offshore nutrient sources and biological productivity
- operating environment for offshore infrastructure (e.g. gas production facilities) and other maritime operations.

2. Continental slope, shelf and coastal processes

To improve understanding of the oceanography, sediment and nutrient flows, and their role in determining ecosystem structure, function and services within the region. This will provide multiple benefits in relation to:

- biodiversity conservation and management
- fisheries recruitment processes and management of the fisheries, pearling and aquaculture
- environmental impact assessment
- managing catchment land use, river discharge and their impacts on the marine environment
- predicting impacts of extreme events (e.g. cyclones) on offshore/ coastal installations; coastal planning.

3. Marine resource and human use inventories

To map and characterise key marine habitats and biological communities, heritage and cultural values, and to document their uses and exposure to human pressures. This will provide benefits for:

- regional marine planning
- biodiversity conservation management (e.g. identification of marine protected areas)
- management of commercial, recreational and Indigenous fisheries and fish habitat areas
- environmental impact assessment
- managing cumulative impacts in multiple use environments
- site selection for aquaculture or industry developments.

4. Baseline, natural variability and long term change in marine ecosystems and their drivers

To monitor change in key drivers and environmental condition indicators within the region. This is important in order to understand the relative importance of natural, climate change and human pressures at various scales within the region. Improved understanding of environmental change and the primary causal factors will provide a better basis for many natural resource management decisions, so that they are properly targeted and more cost-effective.

5. Cause-effect pathways, impact prediction and early warning

To improve understanding of the key processes and pathways linking human-induced pressures with changes in the ecology. This will be of significant benefit in relation to:

- understanding the sensitivities of key species to stress, their recovery potential and the resilience of ecosystems
- identifying early warning indicators of ecological change as triggers for adaptive management
- developing cost-effective surveillance and compliance monitoring systems
- environmental impact prediction and management
- ecosystem-based fisheries management
- predicting the ecological impacts of climate change and managing the adaptation of these ecosystems.

6. Integrated physical, biogeochemical and ecological modeling

To model marine ecosystem behaviour (e.g. hydrodynamics, sediment mobility, marine biological productivity and food web interactions) over broader expanses and in greater detail than permitted by available field data, and to predict the effects of changed environmental conditions or human uses.

7. Planning tools for ecologically sustainable development

Improved decision-making will flow from the integration and application of all the research areas to develop decision-support tools for managers and operators in the region. These tools will include:

- predictive models of the region's marine systems, projections of change due to climate-induced and other anthropogenic pressures, and estimation of socioeconomic responses to these changes
- future scenario and management strategy evaluation to support integrated planning and management.

Table 8. Relative emphasis (in percentages) between the strategic science themes across the four phases of the program

	THEME 1 Values and Assets	THEME 2 Sustaining Processes	THEME 3 Threatening Processes	THEME 4 Scenario Assessment
Phase 1	60	25	10	5
Phase 2	35	40	15	10
Phase 3	25	35	25	15
Phase 4	20	20	30	30

Areas of Focus

Maximum utility should be obtained from existing research and data sets in the region. To this end, WAMSI has co-funded and participated in the preparation of an inventory of scientific data and research on Western Australia's marine and coastal environments, including the Kimberley-Browse marine region (Skewes et al 2008). The inventory has identified that, in specific areas (e.g. in the vicinity of Scott Reef) significant amounts of data are held by resource development companies. Negotiated access to these data would greatly benefit the WAMSI marine science program which, in turn, would result in increased benefits to the public and private sectors. However, the review of science gaps for the region (presented in this report) has demonstrated that the existing research, although very useful, is not able by itself to provide a systematic regional understanding or adequate answers to the management questions posed above.

There is inadequate accuracy and spatial resolution of bathymetric data, particularly in coastal and inner shelf areas of the region. Bathymetric data is an essential requirement for virtually all marine researchers and users. Early attention should be given to improving the bathymetry database (and topographic model linking land to sea), particularly for priority areas of the region.

Initial major priorities for building the science base to support decision-making in the region are proposed below, for each of the themes.

Theme 1: Values and Assets

Initial Priorities

- support Commonwealth/State government joint strategic assessment of national heritage values in the Kimberley (marine component);
- support the Commonwealth/State government joint assessment of a

common-user LNG hub site, assessment of infrastructure layout and formulation of an environmental management system;

- conduct targetted habitat and biodiversity surveys, and establish monitoring programs for baseline, natural variability and long-term change in natural resource condition and human use.

Theme 2: Sustaining Processes

Initial Priorities

Since much of the region's physical and biogeochemical forcings come from large scale ocean-climate processes, early attention should be given to developing an understanding of the region's response to these broader scale influences. Within that regional context, the role of finer scale processes – physical, biogeochemical and ecological – can then be determined for specific areas of agreed high priority.

- initiate an integrated field measurement, data analysis and numerical modelling program to characterise the physical processes which govern climate (including extreme events), marine connectivity, tidal dynamics and sediment mobility in the region;
- initiate an integrated field measurement, data analysis and numerical modelling program to investigate the key *biogeochemical and ecological processes* which govern biodiversity, biological productivity and ecosystem services of the region;
- select several locations of agreed high priority for integrated, high resolution research (e.g. locations subjected to human pressure and 'unimpacted' reference locations);
- initiate research to develop interpretation of remote sensing data for marine properties such as circulation, sea level, surface temperature, turbidity and biological productivity, with particular emphasis on shelf and inshore waters.

Theme 3: Threatening Processes

Initial Priorities

- conduct a risk assessment to identify critical cause-effect pathways for priority research;
- identify environmental requirements of key species and communities;
- investigate critical cause-effect pathways to identify practical, early warning indicators of environmental change and sub lethal response indicators in the marine communities;
- develop classifications for habitat mapping, habitat condition and habitat loss.

Theme 4: Scenario Assessments and Management Strategy Evaluation

Initial Priorities

- assemble research on ecosystems (or key ecosystem processes), human use interactions, climate change, adaptive management strategies and monitoring approaches;
- refine the scope and application of this research in consultation with management agencies and stakeholders;
- identify and address all information requirements.

Theme 5: Marine Monitoring Network and Performance Assessment System

Initial Priorities

- establish a data and information management regime that is open-access via the web;
- design and commence implementation of the first module of the marine observation system in consultation with IMOS, participating resource managers, operators and researchers.

Summary

This report encapsulates nine months of stakeholder consultations to identify the big issues, major decision points and their critical science/ information requirements. During this period state and Commonwealth governments have initiated processes aimed at securing positive regional outcomes in planning, conservation, sustainable use, resource development, adaptation to climate change and joint management with Indigenous peoples.

There has been a sharpening of international and local focus on conserving the exceptional natural and cultural values which attract tourists to the region. The rising costs of energy, coupled with growing climate change concerns, have further emphasised the search for discoverable gas reserves and has again raised possibilities for alternative, renewable energy sources. Effective implementation of these processes, decisions and potential benefits will require a solid foundation of regional science and information.

Stakeholders at the March 2008 Kimberley-Browse Marine Science Policy Summit concluded that there is a clear need for strategic science to develop a systematic understanding of the region to address the challenges of sustainability and climate change, while at the same time delivering timely inputs into ongoing decision-making. The participants believed that WAMSI was a very good vehicle to facilitate the development of a marine science plan for the region and to commence its implementation as a fully funded activity.

research areas

Overview

The following scientific questions are largely unanswered for much of the Kimberley-Browse marine region.

- What are the key natural attributes of the region? Where are they, and what condition are they in?
- What drives and sustains the ecosystems? How do they function and what services do they provide?
- What are the types and intensity of human uses that occur in the region, and where?
- What changes in the ecosystems and human uses are occurring over time?
- How resilient are the ecosystems to natural and human-induced pressures?
- How do human use pressures and climate change affect the environment, and which components are most sensitive to pressure?

The answers to these questions are needed to develop:

- more effective decision support systems to improve conservation outcomes and minimise environmental impact, while providing greater certainty for operators; and
- new methods to assess the cumulative impacts and cost-benefits of alternative planning and management strategies under future human use and climate change scenarios.

The region is remote and presents difficult operating conditions. Field work will be costly. It is important to synthesise existing knowledge, effectively connect emerging science and technology to management needs, and carefully target new field data requirements. Use of an integrated modelling framework coupled with targeted field measurements, and optimising the use of remotely-sensing and autonomous ocean sensors is recommended.

The Kimberley is poorly understood with large information gaps, and dedicated multidisciplinary field programs will be required to address data gaps in the region. Although the marine science requirements are described in terms of seven research areas, there is a strong interrelationship between them all.

Information Requirements within Research Areas

Broadscale Climate and Ocean Processes

The purpose of this research area is to enhance understanding of ocean-climate processes, variability and long-term change in the south east Indian Ocean, and their influence in driving :

- regional climate in the Kimberley-Browse marine region and in the south west of Australia;
- broadscale patterns of marine connectivity between the Kimberley-Browse marine region and surrounding tropical and temperate regions; and
- the biogeochemical and ecological processes operating within the Kimberley-Browse marine region.

This will lead to improved ocean and climate prediction capability, with potential benefits for communities across the Kimberley, south west Australia and south east Asia.

Specifically, this work will improve regional understanding and prediction of the variability and long-term changes in:

- the Australian monsoon;
- the Indonesian Throughflow and regional ocean circulation;
- the intensity and frequency of tropical cyclones;
- rainfall and evaporation;

- sea level, ocean acidification, sea water temperature and salinity;
- biological oceanography of the region; and
- exchange between oceanic and continental shelf waters.

These meteorological and oceanographic influences are key broadscale drivers of the biogeochemical and ecological processes operating within the Kimberley-Browse marine region. Hence, change in these drivers is likely to impact on the marine ecosystems and human uses of the region.

Ocean-atmosphere interactions and climate variability have a profound influence on the terrestrial environment, its ecology and land use (e.g. through changes in rainfall, evaporation, native vegetation, catchment runoff, fire frequency, agricultural production).

The benefits of improved climate prediction will accrue, not only to the Kimberley, but also to much of western and southern Australia, as well as south east Asia.

Continental slope, shelf and coastal processes

The purpose of this research area is to enhance understanding of the physical, biogeochemical and ecological processes which govern ecosystems and human uses on the continental slope, shelf and coastal areas of the Kimberley-Browse marine region.

There is a need to provide critical information and predictive modelling capability on:

- water circulation, currents and wave energy under typical and extreme conditions;
- the transport of nutrients and larvae;
- sediment erosion, transport and deposition on the seabed;
- biogeochemical cycling and biological productivity; and
- habitat dynamics and ecological linkages, including food web interactions.

All of these factors strongly influence the structure and function of marine ecosystems, their productivity, habitats and biodiversity. An understanding of how these processes structure and sustain the marine ecosystems is required for managing the conservation of biodiversity and for sustainable management of uses such as fishing and marine-based tourism. This understanding is also required as part of the environmental impact assessment of coastal and offshore development proposals, to predict marine environmental impacts and assess their significance for the broader ecosystem.

An understanding of many of these processes is critical to the design and operation of coastal and offshore infrastructure, and to the safety of operations at sea. More specific aspects of the information requirements are listed below.

Hydrodynamics

- variability in shelf circulation and longshore flow;
- tidal dynamics and bottom stress;
- mixing processes and frontogenesis (e.g. tidal mixing fronts, river-estuarine plume fronts);
- variability of water column parameters such as temperature, salinity, turbidity and light (in relation to coral bleaching, ecological gradients, etc);
- storm surge and coastal inundation associated with extreme events;
- wave energy distribution (in relation to sediment mobility and benthic habitat exposure);
- projection of hydrodynamic changes for future climate scenarios.

Connectivity

- connectivity of habitats and biological communities between different shelf regions through dispersion of propagules such as larvae.

Sediment Dynamics

- patterns of re-suspension, deposition and sediment transport;

- factors controlling the distribution of sand and mud;
- sediment budgets (is there net accumulation on the shelf?);
- prediction of major sediment transport events associated with extreme events;
- prediction of seabed scour and potential slope failure;
- the fate of terrigenous material, dredge spoil and contaminated sediments;
- changes in sediment dynamics with changing climate.

Productivity

- physical and biogeochemical processes governing nutrient supply;
- relative importance of nutrient supply from riverine inputs, benthic remineralisation and oceanic sources, to regional shelf production;
- relative roles of turbidity (photic zone depth), water column stability and nutrients to primary production, zooplankton and fish larvae;
- develop a biophysical model for the Kimberley shelf region allowing scenario testing for river flow regulation and climate variability.

Habitat Dynamics and Ecological Linkages

- linkage between water circulation regimes, seasonal reproductive activity, larval viability and recruitment dynamics;
- habitat dynamics and the response/ adaptation/recovery of biological communities;
- trophic interactions;
- marine fauna-life cycles and habitat requirements.

Marine Resource and Human Use Inventories

The purpose of this research area is to develop inventories that describe, quantify and map the distribution of ecological, cultural and socioeconomic values/attributes and human uses of the marine environment in the region.

There is a need to collate and integrate existing marine resource and human use data (from government and private sources) and to progressively develop the inventories according to agreed prioritisation criteria. All these data will need to be spatially and temporally referenced and linked to a geographical information system.

It is not possible to plan and manage for a sustainable future in the region without basic knowledge of its natural attributes and cultural values– what they are and where they occur. Similarly, a knowledge of past, current and projected human uses and environmental pressures is essential to management.

Ecological Values/Attributes

Mapping the many natural values and attributes of a region is a large task which needs to be progressed systematically and on a priority basis, according to significance and risk criteria.

The Integrated Marine and Coastal Regionalisation of Australia (Commonwealth of Australia 2006) identified seven marine mesoscale bioregions, two offshore and five coastal, within the Kimberley-Browse marine region. The environmental conditions and marine communities of the offshore and coastal marine bioregions are quite different and there are major differences between the different coastal marine bioregions.

Within each of these bioregions it may be possible to define broadscale 'ecosystem' units (based, for example, on cross-shelf depth zones and coastal morphology) and smaller scale 'habitat' units (based on seabed type, energy exposure and vegetation). In this way, the task of developing marine resource inventories may be approached in a systematic, hierarchical fashion.

The distribution of benthic habitat types and biodiversity is strongly linked to the underlying geology, seabed morphology, sedimentology and exposure to wave and current energy (Geoscience Australia 2006). Modern approaches to compiling marine benthic resource inventories seek to maximise the use of such geophysical 'surrogate' data (which are more cost-effective to measure) together with direct characterisation of the biological communities themselves, at selected sites only. The biological and geophysical data streams can then be analysed together to look for strongly correlated variables which provide the basis for habitat auto-classification schemes. Once developed, these schemes need to be validated against independent biological community data.

In an extension to this approach, it may also be possible to develop and validate biological 'surrogates', for example, associations between particular benthic primary producers and their dependent biological communities.

In very broad terms, inventories of:

- intertidal and subtidal benthic habitat communities (described to the level of their key functional groups);
- fish and planktonic communities; and
- wildlife (their habitat requirements, nursery, resting, feeding areas and migration paths and timing);

are considered to be of highest priority. Further prioritisation would need to occur within these broad categories.

Identifying, mapping and quantifying 'hotspots' of marine endemism presents particular challenges over such a large and biodiverse region. Surrogates may be useful to identify target areas with high habitat diversity and a high probability of significant levels of endemism, however, ultimately it involves the application of taxonomic methods, which is a labour intensive work, made all the more difficult by the current shortage of taxonomists.

In addition to their role in regional marine planning, conservation planning and natural resource management, these inventories also deliver valuable contextual information and tangible benefits in relation to:

- bioactive compounds in marine organisms as the basis of a marine biotechnology industry;
- introduced marine pest management, to avoid or minimise their impacts on the ecology, aquaculture and other maritime infrastructure; and
- managing the impacts of potentially toxic marine species on aquaculture and recreation.

Cultural and Socioeconomic Values/Attributes

Inventories of cultural and socioeconomic values and attributes of the region would include:

- seascapes;
- Indigenous cultural values;
- customary fishing; and
- recreation (e.g. fishing, diving, boating, sightseeing).

Human Uses

These inventories will collate and organise data on the types, locations, timing and intensity of past and current human uses of the marine environment in the region. Information on access to the coast, infrastructure, operations and other activities which have the potential to affect the marine environment or other human uses will be sought.

Using available data and knowledge from the region, the pressures exerted on the surrounding marine environment will be characterised. Where possible, specific pressure-value linkages will be identified and assessed.

Estimates of projected human use patterns into the future will be prepared as part of these inventories.

Baseline, Natural Variability and Long-Term Change in Marine Ecosystems and their Drivers

The purpose of this research area is to develop quantitative baselines of the various physical, chemical, geological and biological components of the system and measurement of how these baselines vary in time and space, producing a picture

of how the system is changing.

Baselines and sustained time-series data should be built up at a limited number of carefully selected sites including nodes of human activity and reference sites (not significantly affected by human activities within the region). These sustained time-series data will provide:

- 'natural variability' benchmarks against which to assess monitoring data from areas influenced by human activities within the region; and
- long-term trends which are occurring at a regional or larger scale (e.g. climate change effects).

There is a need to characterise the variability and long-term trends in key water column, sediment and benthic habitat condition indicators. The time scales of interest range from hours to decades, depending on which components of the system are being considered. In some cases results from other process studies will be required to develop new indicators appropriate to monitoring the health condition of the marine biological communities found in the Kimberley.

Monitoring baseline, variability and long-term trends are an essential elements in effectively managing human impacts on natural systems, assessing resilience to human-induced impacts, recovery rates from extreme events, and devising management strategies to mitigate climate change impacts.

Water Column/Pelagic

Physico-chemical data (e.g. dissolved oxygen, nutrients, pH, light) are sparse across most of the region and there is very little biological oceanographic data available.

Quantification of seasonal and inter-annual variability in physical and biological water column characteristics is needed to understand productivity and the environmental requirements of biological communities. Sustained, systematic monitoring in the pelagic system is required to detect long-term trends associated with climate variability, climate change, and possible anthropogenic influences.

These data could be used to calibrate and validate remotely-sensed ocean colour datasets, to provide much more extensive information on chlorophyll a distributions in the region. The calibration and validation work will be of particular importance over the inner shelf and near-shore areas of the Kimberley, where shallow water and large concentrations of suspended sediments complicate interpretation of the ocean colour signal.

Benthic Habitats and Communities (e.g. coral reef, seagrass and filter feeder communities)

Little is known of the structure, ecological zonation and condition of benthic communities. This can be addressed by establishing sets of re-locatable transects (e.g. along depth gradients) at several reference locations across the region, and conducting repeatable quantitative surveys of abundance, diversity and community structure along these transects. For the more prominent habitats and communities, remotely operated vehicles (ROV), towed videos and drop cameras could be used to circumvent the difficulties of diving in some areas. Other techniques would need to be developed for sampling benthic infauna.

This would provide a basis for resolving seasonal and inter-annual variability in community structure and condition of benthic communities. It would also provide an opportunity to investigate resilience and impact – recovery pathways and timescales associated with extreme events (e.g. physical damage due to cyclones, or coral bleaching induced either by heat or freshwater discharge).

Palaeorecord

There are very few places in the Kimberley-Browse marine region where systematic time-series measurements of environmental change are being made, and even then, the length of these records is a few years at most.

Fortunately, some biological communities preserve a detailed record of their exposure to previous environmental conditions. For example, measurement and analyses of growth characteristics in long living coral colonies can provide insights

into coral responses to climatic change and environmental stresses over the past several centuries. Analysis of the geochemical composition of the coral skeleton can also provide 'proxies' for sedimentation, water temperature, salinity and acidity, extending back several centuries (Australian Institute of Marine Science 2008).

Cause-effect Pathways, Impact Prediction and Early Warning

The purpose of this research area is to develop an adequate understanding of the relationships between human use pressures and their potential impacts on the values of the region.

This will enable development of impact prediction models and monitoring methods which feed back into adaptive management of human use pressures on the environment, and to assess trade-offs amongst different activities.

The tolerance, response and recovery potential of marine communities in the region to both natural and human-induced stress is poorly understood. While some guidance may be provided by studies conducted elsewhere, there will be a need to study the threatening processes and responses of the most sensitive key species and communities in the region that are at risk. This will most likely involve studies along environmental gradients and the use of manipulative experiments (e.g. to assess the impacts of enhanced sedimentation on coral communities).

It will also be important to identify key linkages between ecosystem components, because an impact on one component may result in 'knock on' effects to other ecosystem components.

A key outcome of this research will be to identify appropriate performance measures (i.e. indicators) early in the human pressure-environmental receptor pathways and provide the capacity for setting management targets (usually the 'natural state' or some acceptable departure from the 'natural state').

This research is needed to develop monitoring methodologies and designs which are robust, transportable, capable of representing ecosystem health condition, detecting early-warning signs of change (or impact), delineating the spatial extent of the change and the time scale required for recovery from impacts.

This research will be used for conservation planning, natural resource management and environmental impact assessment.

Integrated Physical, Biogeochemical and Ecological Models

The purpose of this research area is to develop and validate an integrated set of physical, biogeochemical and ecological models for the Kimberley-Browse marine region.

The physical models include water circulation, ocean wave and sediment transport models. The biogeochemical models seek to represent the material stores and fluxes of carbon and nutrients, and their interactions with the biota. Ecological models may include targeted cause-effect pathway models or more general food web models.

At a conceptual and schematic level, models can be used to foster communication and linkages between multiple research teams and enhance integration of science outcomes.

Quantitative simulation models should be developed and applied in consultation with each of the marine science teams to guide the design of research and field measurement programs, test understandings derived from field data analyses, and validate model performance against field data.

Validated models can be used to characterise system behaviour at finer spatial and temporal resolution than permitted by available field data; estimate materials/energy fluxes and budgets, and simulate the biological effects of changed environmental conditions.

The lack of accurate data to specify conditions around their open (sea) boundaries can be a major factor limiting the prediction skill of water circulation models, which feed data into most of the other types of models. This issue can now be addressed by nesting finer spatial resolution models within a global, data assimilating model designed to simulate the circulation and water column structure of the

ocean beyond the continental shelf. Current data assimilation schemes deal with physical variables (e.g. sea surface height and temperature) derived from satellite and autonomous ***in situ*** instruments and are used in conjunction with ocean circulation models. In the future biogeochemical variable may also be able to be assimilated.

Scenario Assessments and Management Strategy Evaluation

The purpose of this research area is to develop regional scenario assessments and management strategy evaluation methods which provide a framework that can be used to compare the outcomes of alternative management strategies and future scenarios against ecological and socioeconomic targets. Such a framework brings together models of ecosystems (or key ecosystem processes), human use interactions, management strategies and monitoring approaches. It provides a focus for integrating the data and understanding from all of the research areas and incorporates uncertainty. The goal is to assist planners and managers to explore and assess the relative risks and implications of alternative strategies and scenarios prior to making decisions.

It must be stressed, however, that the practical utility of these methods will depend heavily upon the availability of fundamental data sets which characterise the resources, ecosystems and human uses in this poorly understood region.

science management and infrastructure requirements

Governance, Coordination and Planning

A high level of planning, collaboration, coordination and resourcing across government agencies, private organisations and marine science providers, underpinned by sound governance structures, will be required to deliver the necessary knowledge, understanding and decision support tools for the region.

Clarity and joint ownership of vision, objectives, science themes, research areas, roles and responsibilities and how the research teams interact to meet the overall objectives is essential. This will need to be constantly emphasised through informal interactions and structured means of communication and reporting between participants.

The broad scope and objectives of the proposed strategic science program for the Kimberley-Browse marine region will draw on knowledge, understanding and information from various research disciplines (both the natural and social sciences), sectors of society (both Indigenous and non Indigenous), end-users and government agencies. Some of these areas are beyond the remit of WAMSI's core research activities. This is not a new situation for WAMSI, however, as instanced by its collaboration with the CRC for Sustainable Tourism to develop a tourism information model and an environmental-flows model for the Ningaloo Reef. The Kimberley-Browse marine science program will also require research collaboration and the formation of new alliances between WAMSI and other research organisations.

It will be important to maintain dialogue with stakeholders during the planning process to ensure that focus and relevance is maintained. It is also likely that stakeholders will be able to value-add to the program through in kind support and collaboration.

Utilisation of major infrastructure and capabilities may require considerable lead times. It will be important that the strongest possible case be made, based on optimising the use of these facilities.

Realistically, the planning process (definition of projects, tasks, research teams, allocation of resources) is likely to take 12 months from the formal inception of the project. As mentioned elsewhere, this can coexist with data gathering programs designed to service urgent government priorities, provided funding is made available for these programs.

Indigenous Involvement and Participation

Indigenous involvement and participation should be considered in planning and conducting marine monitoring and research programs. This may take the form of consultations, seeking permissions (to access land or conduct research), promoting the preservation and appropriate transfer of Indigenous coastal knowledge, traineeships and scholarships.

Data Protocols, Data Management and Information Systems

In a highly interactive project it will be important that data, model results and information generated can be transferred and used effectively by participating research teams, government agencies and private organisations, as appropriate. Hence it will be important to adopt standard data protocols. Data must be archived and managed by professionals and ready access to information facilitated. Long-term data archiving and retrieval systems will be needed to assure the preservation of the data for long-term use. Discovery, data visualisation and analysis tools such as geographic information systems will be necessary.

Science Infrastructure

The Kimberley-Browse marine region is a large, remote area which presents difficulties of access and difficult operating conditions. Marine research methods commonly used in other areas (e.g. scuba) cannot be automatically assumed to be appropriate for this region. Amongst these difficulties are the turbidity of near-shore waters, the strong tidal currents and the presence of crocodiles. It is over 300 km from Broome to the Rowley Shoals and other shelf edge atolls.

Research Vessels

Desirably, two of Australia's major oceanographic research vessels would be required as platforms to conduct some of the research in the extensive Kimberley-Browse marine region. The RV *Southern Surveyor* is a national facility available to marine scientists to explore and study Australia's oceans. It is owned and managed by CSIRO, and its operations are funded by the Commonwealth government to enable oceanographic, geo-science, fisheries and ecosystem research. The *Southern Surveyor* will end its operational life around 2011, and it is still unclear how this capability will be replaced. AIMS recently commissioned a new research vessel RV *Solander* which allows for an increased complement of 18 people, which will increase collaboration with other organisations such as Geoscience Australia, CSIRO, universities and government agencies. The *Solander* is well equipped for oceanographic research and has modern equipment to map the sea floor, visualise the sea bottom, survey marine resources and map biological communities in deep water.

Logistics support should also be sought from Australian Customs Service vessels, Department of Fisheries patrol vessels and charter/service vessels in the region. Several of these vessels are proven platforms for state-of-the-art habitat mapping and biodiversity assessments in coastal waters. It may also be possible to mount autonomous sensors and logging systems on vessels servicing the tourism, pearling and offshore oil and gas industries. Smaller boats will be required for work in inshore and intertidal areas.

Sustained Observations

Lack of sustained observations of the atmosphere and oceans have hindered the development and validation of climate and marine forecasting models. However, the past decade has witnessed dramatic advances in ability to observe the oceans. Prior to the 1990s, ocean observations relied almost exclusively on ship-borne measurements and moored instruments. Today, most open ocean observations are gathered by satellite-borne altimeters and radiometers, and by autonomous profiling floats. This advance has dramatically increased capacity to monitor, forecast and re-analyse the ocean circulation (Oke & Schiller 2007).

As part of an international effort, Australia is developing IMOS, a nation-wide collaborative program designed to observe the coastal and open oceans around Australia (Integrated Marine Observing System 2007). Funded by the Commonwealth government through the National Collaborative Research Infrastructure Strategy, IMOS will provide data to support research on many of the critical marine issues facing Australia, including climate change, offshore operations and sustainability of ecosystems. IMOS provides an enhanced, nationally-integrated capacity to collect marine data, draw it together and make it accessible to researchers and other users. IMOS partners comprise most of the agencies and universities with capability in ocean and marine research – many of these are also partners in WAMSI. Amongst the facilities being built up by IMOS are :

- Argo – autonomous floats to collect open ocean temperature, salinity and current data.
- The Australian National Mooring Network – a series of national reference stations and regional moorings which provide long-term time series meteorological, oceanographic and biophysical observations in coastal, shelf and slope seas. Data from these reference stations can also be used to provide reliable calibration for coastal and ocean colour satellite mission data sets and validation for circulation and wave models.

- Australian Coastal Radar Network – HF radar provides unprecedented time-resolved surface current maps over the monitoring sites for physical and biological ocean research.
- Australian Acoustic Tagging and Monitoring System (AATAMS) – Acoustic monitoring is a powerful tool for observing tagged marine animals with networks or cross-shelf arrays (curtains) of receivers, allowing animals to be monitored over scales of hundreds of metres to hundreds of kilometres.
- Facility for Automated Intelligent Monitoring of Marine Systems (FAIMMS) – will have the ability to return spatially dense bio-physical measurements in real-time. Valuable for small scale ecological work.
- Marine data and information are the main products of IMOS, and data management is therefore a central element to the project's success. The eMII facility will provide a single integrative framework for data and information management that will allow discovery and access of the data by scientists, managers and the public. Data will be archived within the Australian Ocean Data Network (AODN), which is a distributed data storage and discovery network based at leading Australian marine research facilities.

In Western Australia, a consortium comprising WAMSI, iVEC (the hub of advanced computing in Western Australia) and WASTAC (Western Australian Satellite Technology and Applications Consortium) have together established a WA Node of the AODN (Australian Oceanographic Data Network) for the discovery and access to WA marine data (using MEST and iVEC resources). A marine data manager has been employed to assist with data/metadata quality assurance and quality control tasks. Marine data sets are already being loaded onto iVEC.

Marine remote sensing, or satellite oceanography, provides data on ocean surface characteristics, including sea level, surface temperature and amounts of phytoplankton that are an invaluable complement to information collected from ships.

Satellite-based measurements of sea level height (e.g. Jason-2 Ocean Surface Topography Mission), surface temperature and salinity are needed to understand regional ocean circulation, improve climate forecasts and measurements of global sea level changes.

Parameters derived from satellite ocean colour data provide information about the water content and its optical properties, relevant to measuring the distribution of chlorophyll concentration and primary production. Ground truthing and calibration of ocean colour data in shallow seas is a priority area.

Data Assimilation into Models

Data assimilation is a method for greatly enhancing the information available from satellite and *in situ* data to provide a detailed three-dimensional and time varying knowledge of the 'state of the ocean'. Assimilation combines observations with detailed computer models in a way that ensures that the results agree with the fundamental physical laws that govern ocean dynamics.

The Bluelink program (Bureau of Meteorology 2008) is a partnership between the Bureau of Meteorology, CSIRO and the Australian Navy. It has developed the first Australian operational forecast and re-analysis system of the mesoscale ocean circulation around Australia. The data assimilation schemes used in Bluelink are at the forefront of ocean analysis and forecasting technology worldwide. Because Bluelink is a recent development, there is a need to assess and validate its products in strategically important areas such as the offshore Kimberley-Browse marine region. Its application will improve understanding of broadscale ocean processes and the role they play in affecting climate change, offshore operations and sustainability of ecosystems.

An extremely useful application of the Bluelink open ocean model will be its ability to provide realistic data at the sea boundaries of nested finer spatial scale models of the shelf and coastal waters. These finer scale models are required for predicting the occurrence of phenomena such as internal waves,

storm surge, coral bleaching, sediment transport and nutrient upwelling.

Multibeam Sonar

Australia is custodian to a large marine jurisdiction with associated seabed habitats that need to be managed for multiple use purposes. Mapping seabed habitats or their surrogates is a fundamental first step in this process, with methods that can map large areas of seabed such as multibeam swath mapping sonars representing attractive tools. These can be used in conjunction with biophysical, geophysical and video/photographic devices (Kloser & Penrose 2000).

Several multibeam sonar systems are now capable of collecting and recording data samples covering the full water column, not just the seabed. Full water column multibeam data sets are valuable to scientists from traditionally diverse fields, providing simultaneous information about bathymetry, seabed type and habitats, and biomass in the water column.

Logistics and Operational Issues (OHS)

The pearling, oil and gas, and other offshore industries have marine operational experience in the region, as do several of the WAMSI member organisations. It is recommended that WAMSI draw to the attention of its research provider members the need for careful planning and implementation of safe, effective operations and contingency plans (e.g. emergency personnel evacuation and medical assistance) in this remote and demanding environment. Occupational health and safety protocols and practices in particular should be given the utmost priority.

Due to strong tides, turbid inshore waters and other risks inherent to the region (e.g. crocodiles), scientists are likely to consider alternative sub surface observational methods to diving (e.g. towed or drop photographic techniques).

The Pearl Producers Association (McCallum, B. pers comm 2008) has advised that all the pearling health and safety issues around diving have been developed in-house by the industry. The pearling industry purchased and operates a recompression chamber in Broome Hospital. All training of doctors, nurses and chamber operators, as well as maintenance and consumables is at pearling industry direct cost. The industry has developed its own dive tables to meet the specific requirements of pearl oyster collection by diving in the Kimberley/Pilbara regions. This incorporates a full time safety officer in Broome running induction courses for prospective pearl divers before they are employed. Decisions by other industries and governments to operate divers in the region will need to develop an arrangement with the pearling industry for access to the recompression chamber, if that is their plan.

Integration and Delivery

The proposed WAMSI Kimberley science program will need to focus on cohesion, communication, integration and delivery of information to decision-making processes in a form that will make a difference. Achievement of objectives requires appropriate governance systems and structures. WAMSI has developed these through the work of its Board of Governors, its system of reporting and evaluating, its system of peer review and the use of integrated research nodes. These strong structures and business processes demonstrate its capacity to achieve the objectives collaboratively with cooperation across disciplinary and jurisdictional boundaries.

conclusion

The marine biodiversity, ecological integrity and cultural heritage of the Kimberley-Browse marine region is of global significance. Industries such as tourism, fisheries, pearling and aquaculture, which rely on a healthy marine environment, play a vital part in the regional economy and social life. The region has abundant energy and mineral resources and production of offshore petroleum and natural gas can be expected to accelerate rapidly over the coming years. Climate change will impact on the ecosystems, the communities and the economy of the region. The extent and severity of these impacts is yet to be fully quantified.

Decisions facing governments and all of the stakeholders in the Kimberley-Browse marine region overlap jurisdictional boundaries and have environmental, social and economic implications. Research is needed that can achieve outcomes in the short-term and also build a base so that ongoing results can be applied to future decision-making and management of the region.

The scope of the science needed to understand and manage the ecology in the face of growing pressures, both from the activities in the region and the effects of climate change, is well beyond what can be achieved by one-off projects. A coordinated, interdisciplinary science program capable of addressing regional to local scale issues is needed to support better decisions, now and into the future.

Stakeholders at the March 2008 Kimberley-Browse Marine Science Policy Summit concluded that there is a clear need for strategic science to develop a systematic understanding of the region to address the challenges of sustainability and climate change, while at the same time delivering timely inputs into ongoing decision-making. The participants believed that WAMSI is a very good vehicle to facilitate the development of a marine science plan for the region and to commence its implementation as a fully funded activity.

bibliography

Allen Consulting Group. (2005). *Climate change risk and vulnerability: Promoting an efficient adaptation response in Australia*. Report to the Australian Greenhouse Office by the Allen Consulting Group.

Andrewartha, J., Condie, S., Hart, A., & Mansbridge, J. (2006). Transport and recruitment of silver-lip pearl oyster larvae on Australia's North West shelf. *Journal of Shellfish Research* .

ANZECC TFMPA. (1998). *Guidelines for Establishing the National Representative System of Marine Protected Areas*. Canberra: Australian and New Zealand Environment and Conservation Council, Task Force on Marine Protected Areas, Environment Australia.

Australian Institute of Marine Science. (2008). *Climate and environmental histories from coral*. Retrieved May 7, 2008, from Australian Institute of Marine Science: http://www.aims.gov.au/docs/research/climate-change/climate-history/climate-history.html

Australian Institute of Marine Science. (2007). *Research Plan 2007-2011*. Townsville, Queensland: Australian Institute of Marine Science.

Bax, N. J., & Williams, A. (2001). Seabed habitat on the southeast Australian continental shelf –context, vulnerability and monitoring. *Marine and Freshwater Research*, 52: 491-512.

Braimbridge, M. J., & Malseed, B. E. (2007). *Ecological water requirements for the lower Ord river*. Department of Water, Government of Western Australia.

Brewer, D. T., Lyne, V., Skewes, T. D., & Rothlisberg, P. (2007). *Trophic Systems of the North West Marine Region*. Report to the Department of the Environment and Water Resources: CSIRO Cleveland.

Bureau of Meteorology. (2008). *BLUElink Ocean Forecasting Australia*. Retrieved May 8, 2008, from Bureau of Meteorology: http://www.bom.gov.au/bluelink/

Collins, J. (2008). Marine Tourism in the Kimberley Region of Western Australia. *Geographical Research, 46 (1)* , 111-123.

Commonwealth Government. (2007). *Fisheries A to Z*. Retrieved July 25, 2008, from Australian Fisheries Management Authority: http://www.afma.gov.au/fisheries/fisheries_index.htm

Commonwealth of Australia. (2006). *A Guide to the Integrated Marine and Coastal Regionalisation of Australia Version 4.0*. Canberra, Australia: Department of the Environment and Heritage.

Commonwealth of Australia. (1996). *National strategy for the conservation of Australia's biological diversity*. Canberra: Department of the Environment, Sport and Territories.

CRC Reef. (2003). *The Value of biodiversity*. Retrieved May 14, 2008, from CRC Reef –Reef Futures: http://www.reeffutures.org/topics/biodiversity/value.cfm

Cresswell, G. R., & Badcock, K. A. (2000). Tidal mixing near the Kimberley coast of NW Australia. *Journal of Marine and Freshwater Research* , 51(7) 641 –646 .

CSIRO. (2007). *Australian offshore mineral locations map*. Retrieved May 12, 2008, from About CSIRO: http://www.csiro.au/resources/ps2et.html

Department of Environment and Conservation. (2006). *Draft – A 100-year Biodiversity Conservation Strategy for Western Australia: Blueprint to the Bicentenary in 2029*. Government of Western Australia.

Department of Fisheries. (2003). *Aboriginal Fishing Strategy: "Recognising the past, fishing for the future".* Perth, Western Australia: Fisheries Management Paper No. 168.

Department of Planning and Infrastructure. (2006). *Port Handbook*. Retrieved May 7, 2008, from Department of Planning and Infrastructure, Government of Western Australia: http://www.dpi.wa.gov.au/seafreight/1336.asp

Department of the Environment and Water Resources. (2007). *A Characterisation of the Marine Environment of the North west Marine Region.* Draft: A summary of an expert workshop convened in Perth, Western Australia, 5-6 September 2007.

Department of the Environment, Water, Heritage and the Arts. (2008). *Marine Bioregional Planning***.** Retrieved May 8, 2008, from Department of the Environment, Water, Heritage and the Arts: http://www.environment.gov.au/coasts/mbp/index.html

Department of the Environment, Water, Heritage and the Arts. (2008). *Marine Bioregional Planning in the North west.* Retrieved May 9, 2008, from Department of the Environment, Water, Heritage and the Arts: http://www.environment.gov.au/coasts/mbp/north west/index.html

Dracup, M., McKellar, R., & Ryan, B. (2005). *Living with our changing climate (IOCI Workshop Proceedings).* Perth: Indian Ocean Climate Initiative.

Environmental Protection Authority. (2008). *Marine*. Retrieved June 21, 2008, from State of the Environment Report Western Australia 2007: http://www.soe.wa.gov.au/report/marine.html

Fletcher, W. J. (2006). Frameworks for Managing Marine Resources in Australia through Ecosystem Approaches: Do they Fit together, and are they useful? *Bulletin of Marine Science 78 (3)* , 691-704.

Fletcher, W., & Head, F. (2006). *State of the Fisheries Report 2005-2006***.** Perth: Department of Fisheries, Government of Western Australia.

Gehrke, P. (2007). *Ecological Patterns and Processes in the Lower Ord River and Estuary.* Draft Report for NRM Rangelands Coordinating Group: CSIRO Land & Water, Australia.

Geoscience Australia. (2006). *Classifying Australia's seascapes for marine conservation*. Retrieved May 9, 2008, from Geoscience Australia AusGeo News: http://www.ga.gov.au/ausgeonews/ausgeonews200612/conservation.jsp

Godfrey, J. S., & Mansbridge, J. V. (2000). Ekman transports, tidal mixing, and the control of temperature structure in Australia's northwest waters. *Journal of Geophysical Research–Oceans* , 105: 24021-24044.

Government of South Australia. (2007). *Coasts and marine –Marine Planning***.** Retrieved May 11, 2008, from Department for Environment and Heritage: http://www.environment.sa.gov.au/coasts/pdfs/mp_framework_overview.pdf

Government of Western Australia. (2008). Retrieved May 9, 2008, from Marine Regional Planning: http://rmp.naturebase.net/

Government of Western Australia. (2008). *Integrated Fisheries Management*. Retrieved July 25, 2008, from Department of Fisheries: http://www.fish.wa.gov.au/sec/man/index.php

Government of Western Australia. (2006). *Kimberley Economic Perspective. An update on the economy of Western Australia's Kimberley Region.* Perth: Kimberley Development Commission and Department of Local Government and Regional Development.

Hallegraeff, G. M., & Jeffrey, S. W. (1984). Tropical phytoplankton species and pigments of continental shelf waters of north and north west Australia. *Marine Ecology. Progress Series*, 20: 59-74.

Holmes, G. (2004). *Draft Kimberley Natural Resource Management Plan***.** Produced for the WA Rangelands NRM Coordinating Group.

Inpex Browse Ltd. (2007). *Ichthys Gas Field Development. EIS/ERMP: Environmental Scoping/Guidelines for the Proposed Ichthys Gas Field Development.* Document No. DEV-EXT-RP-0014.

Integrated Marine Observing System. (2007). *Introducing IMOS.* Retrieved May 8, 2008, from IMOS Integrated Marine Observing System: http://www.imos.org.au/

International Coral Reef Action Network. (2006). *Third International Tropical Marine Ecosystem Management Symposium***.** Retrieved May 12, 2008, from International Coral Reef Action Network: http://www.icran.org/pdf/ITMEMS%203%20WRITTEN%20PROCEEDINGS%20-%20FINAL.pdf

Jenner, K. C., Jenner, M.-N., & McCabe, K. A. (2001). Geographical and temporal movements of humpback whales in Western Australian waters. *APPEA Journal* , 38 (1):692-707.

Jernakoff, P., & Wells, F. (2006). An Assessment of the Environmental Impact of Wild Harvest Pearl Aquaculture (Pinctada Maxima) in Western Australia. *Journal of Shellfish Research* , 141–150 .

Johnson, J. E., & Marshall, P. A. (2007). *Climate Change and the Great Barrier Reef: a vulnerability assessment.* Australia: Great Barrier Reef Marine Park Authority and Australian Greenhouse Office.

Joint Ministerial Press Statement. (2008, February 5). *Big Picture Study of Australia's Kimberley***.** Retrieved May 8, 2008, from Minister for the Environment, Heritage and the Arts: http://www.environment.gov.au/minister/garrett/2008/pubs/mr20080205.pdf

Kloser, R. J., & Penrose, J. D. (2000). Optimal seabed habitat mapping using multibeam acoustics with associated physical and visual sampling devices – at sea trials. *Australian Acoustical Society Conference Proceedings.* Joondalup, Western Australia.

Land & Water Australia. (2007). *About us –Tropical Rivers and Coastal Knowledge*. Retrieved May 17, 2008, from TRaCK: http://www.track.gov.au/about.html

Last, P., Lyne, V., Yearsley, G., Gledhill, D., Gomon, M., Rees, T., et al. (2005). *Validation of the national demersal fish datasets for the regionalisation of the Australian continental slope and outer shelf (>40 m depth).* Australia: Department of Environment and Heritage and CSIRO Marine Research.

Marine Coastal Community Network. (2008). *Kimberley Marine and Coastal Scientific Forum 2008: A focus on science.* Murdoch University, Western Australia: DVD Marine Coastal Community Network and North West Research Association.

Mustoe, S., & Edmunds, M. (2008). *Coastal and Marine Natural Values of the Kimberley***.** Produced for WWF-Australia.

NAILSMA. (2006). *Dugong and Marine Turtle Management* . Retrieved May 17, 2008, from About NAILSMA: http://www.nailsma.org.au/projects/dugong_turtle.html

National Land and Water Resources Audit. (2001). *Australian Water Resources Assessment 2000***.** Canberra: NLWRA.

Oke, P. R., & Schiller, A. (2007). Impact of Argo, SST, and altimeter data on an eddy-resolving ocean. *Geophysical Research Letters Vol. 34, L19601, doi:10.1029/2007GL031549* , 1-7.

Parslow, J., Margvelashvili, N., Palmer, D., Revill, A., Robson, B., Sakov, P., et al. (2003). *The response of the Lower Ord River and estuary to management of catchment flows***.** OBP Project 3.4/4.1/4.2 Final Science Report to Land and Water Australia: CSIRO.

Pearl Producers Association. (2007). *Media Release*. Retrieved May 7, 2008, from Western Australian Fishing Industry Council: http://www.wafic.com.au/images/wafic---iehet.pdf

Ponder, W., Hutchings, P., & Chapman, R. (2002). *Overview of the Conservation of Australian Marine Invertebrates.* A Report for Environment Australia: Australian Museum. Sydney, Australia.

Post, A. L., Wassenburg, T., & Passlow, V. (2006). Physical surrogates for macrofaunal distributions and abundance in a tropical gulf. *Marine and Freshwater Research* , 57(5): 469-483.

Potter, A., Baker, C., Tran, M., & Heap, A. (2008). Geomorphology and Sedimentology of the Northwest Marine Region of Australia. *Geoscience Australia, Record 2007, Canberra* .

Rothlisberg, P. C., & Church, J. A. (1994). Processes controlling the larval dispersal and postlarval recruitment of penaeid prawns. In P. W. Sammarco, & M. L. Heron, *Bio-Physics of Marine Larval Dispersal (*pp. 235-252). Washington, DC, USA: American Geophysical Union.

Scherrer, P., Smith, A., & Dowling, R. (2008). *Tourism and the Kimberley coastal waterways. Environmental and cultural aspects of expedition cruising.* CRC for Sustainable Tourism Pty Ltd.

Simpson, C. J., Colman, J. G., & Hill, A. K. (2002). *A strategic framework for marine research and monitoring in the Shark Bay World Heritage Property. Crawley, WA*: Department of Conservation and Land Management.

Smyth, D. (2007). *Sea Countries of the North west.* Report prepared for the National Oceans Office Branch, Marine Division, Australian Department of the Environment and Water Resources.

Stroud, S., & Steedman, R. (2002). *Draft: Timor Sea Focus Area and PIT –WAGOOS Initiative.* Retrieved May 18, 2008, from WAGOOS: http://www.bom.gov.au/wagoos/documents/workshop_17_september_2002_pit_paper_stroud.pdf

Volkov, D. L., Larnicol, G., & Dorandeu, J. (2007). Improving the quality of satellite altimetry data over continental shelves. *Journal of Geophysical Research* , 112, C06020, doi:10.1029/2006JC003765.

Wilson, B. (1994). *A Representative Marine Reserve System for Western Australia: Report of the Marine Parks and Reserves Selection Working Group***.** Como: Department of Conservation and Land Management, Government of Western Australia.

Wolanski, E., Moore, K., Spagnol, S., D'Adamo, N., & Pattiaratchi, C. (2001). Rapid, human-induced siltation of the macro-tidal Ord River estuary, Western Australia. *Estuarine, Coastal and Shelf Science* , 53, 717-732.

Woodside Energy. (2008). *EPBC Act Referral of Proposed Action: Browse Upstream Development*. Woodside Energy Ltd, February 2008.

appendix 3

Acknowledgments

Many contributions were made to this work. Thanks are due to the WAMSI board, committees, executive, secretariat and researchers, public and private sector policy-makers and scientists who gave the project their time and in particular those who attended the science policy summit in March.

WAMSI Stakeholder Reference Group

Dr Barry Carbon	Chairman
Dr Peter Rogers	WAMSI, Chairman
Dr Steve Blake	WAMSI, CEO
Dr Ian Cresswell	Department of the Environment, Water, Heritage and the Arts
Mr Richard Ellis	Australian Petroleum Production and Exploration Association Ltd (APPEA)
Mr Paul Gamblin	World Wildlife Fund (WWF)
Ms Priscilla Hubbard	Woodside Energy Ltd
Mr Brett McCallum	Pearl Producers Australia
Mr Ceri Morgan	Independent Environmental Consultant to Kimberley Land Council (KLC)
Mr Greg Oliver	INPEX Browse Ltd
Mr Duncan Ord	Department of Industry and Resources, Northern Development Taskforce
Dr Chris Simpson	Department of Environment and Conservation
Dr Luke Smith	Woodside Energy Ltd
Ms Paula Tomkins	Department of the Environment, Water, Heritage and the Arts (WA)
Dr Kate Wilson	CSIRO
Mr Simon Woodley	Australian Institute of Marine Science (WA)

WAMSI Node Leaders

Node 1	Dr John Keesing	CSIRO Division of Marine and Atmospheric Research
Node 2	(currently)	Dr Ming Feng CSIRO, Climate Change
	(formerly)	Dr Bryson C. Bates CSIRO, Climate Change
Node 3	Dr Chris Simpson	Department of Environment and Conservation
Node 4	Dr Rick Fletcher	Department of Fisheries
Node 5	(currently)	Ms Fiona vom Berg Department of Fisheries
	(formerly)	Dr Chris Battershill Australian Institute of Marine Science
Node 6	Prof. Greg Ivey	The University of Western Australia

Summit Attendees

Dr Bryson Bates	CSIRO, Climate Program
Dr Chris Battershill	Australian Institute of Marine Science (AIMS)
Dr Steve Blake	Western Australian Marine Science Institution
Dr Bernard Bowen	WAMSI, Strategic Projects Committee
Dr Clay Bryce	WA Museum
Mr Barry Carbon	Chairman, Stakeholder Reference Group
Mr Richard Costin	Kimberley Media
Dr Ian Cresswell	Department of the Environment, Water, Heritage and the Arts
Dr Nick D'Adamo	Bureau of Meteorology
Dr Ian Elliot	Department of Environment and Conservation

Dr Rick Fletcher	Department of Fisheries
Dr Jane Fromont	Western Australian Museum
Mr Paul Gamblin	WWF Australia
Dr Kriton Glenn	Geoscience Australia
Dr Roy Green	WA Government Taskforce for Greenhouse Energy
Dr Michael Hughes	Geoscience Australia
Mr Glenn Hurry	Australian Fisheries Management Authority
Dr John Keesing	CSIRO, Marine & Atmospheric Research
Prof. Paul Lavery	Edith Cowan University
Dr Ray Masini	Department of Environment and Conservation
Dr Peter McCafferty	Chemistry Centre (WA)
Mr Brett McCallum	Pearl Producers Association
Ms Linda McGowan	Western Australian Marine Science Institution
Mr Keiran McNamara	Department of Environment and Conservation
Mr Peter Millington	Department of Fisheries WA
Mr Ceri Morgan	Kimberley Land Council
Ms Aileen Murrell	WA Chamber of Minerals and Energy
Mr Greg Oliver	INPEX Browse Ltd
Mr Duncan Ord	Department of Industry and Resources, Northern Development Taskforce
Ms Donna Petrachenko	Department of the Environment, Water, Heritage and the Arts
Prof. Chari Pattiaratchi	University of Western Australia
Ms Annie Phillips	Kimberley Land Council
Dr Ian Poiner	Australian Institute of Marine Science
Mr Jeff Ralston	Pearl Sea Coastal Cruises
Prof. Jim Reynoldson	Murdoch University
Prof. Alistar Robertson	University of Western Australia
Dr Peter Robertson	Wilderness Society
Dr Peter Rogers	WAMSI Board of Governors
Ms Annabell Sandes	Kimberley Whale Watching
Dr Chris Simpson	Department of Environment and Conservation
Dr Luke Smith	Woodside Energy Ltd
Mr Graeme Stewart	Western Australian Fishing Industry Council Inc. (WAFIC)
Dr Chris Tallentire	Conservation Council WA
Mr Charlie Thorn	Curtin University of Technology
Mr Peter Viney	Department of Industry and Resources
Dr Paul Vogel	Environmental Protection Authority
Dr Steve Waller	Department of Environment and Conservation, Office of Climate Change
Dr Tim Willing	Kimberley Naturalist Expert with Pearl Sea Coastal Cruises
Dr Barry Wilson	Murex Consultants Pty Ltd
Dr Kate Wilson	CSIRO, Wealth from Oceans Flagship
Mr Robin Wright	BHP Billiton Petroleum

Stakeholder Meetings

Dr Greg Ayers	CSIRO, Marine & Atmospheric Research
Ms Eve Bunbury	WA Department of Fisheries
Mr David Baird	Australian Maritime Safety Authority
Dr Bryson Bates	CSIRO, Climate Program

Mr Ted Bowen	Geoscience Australia
Mr Charlie Brister	Department of the Environment, Water, Heritage and the Arts
Dr Brendan Brooke	Geoscience Australia
Mr Barry Carbon	Regional Marine Planning Stakeholder Reference Group
Mr Keith Claymore	WA Department of Environment and Conservation
Mr John Collins	Tourism WA
Dr Ian Cresswell	Department of the Environment, Water, Heritage and the Arts
Dr Peter Craig	CSIRO, Marine & Atmospheric Research
Dr Nick D'Adamo	Intergovernmental Oceanographic Commission of UNESCO
Ms Nancy Dahl-Tacconi	Department of the Environment, Water, Heritage and the Arts
Mr James Duggie	WA Office of Climate Change
Dr Ming Feng	CSIRO, Climate Program
Prof. John Finlay-Jones	Edith Cowan University
Mr Mark Flannigan	Department of the Environment, Water, Heritage and the Arts
Dr Rick Fletcher	WA Department of Fisheries
Dr Clinton Foster	Geoscience Australia
Dr James Gilmour	Australian Institute of Marine Science (AIMS)
Dr Kriton Glenn	Geoscience Australia
Dr Peter Harris	Geoscience Australia
Dr Andrew Heyward	Australian Institute of Marine Science (AIMS)
Dr Andrew Heap	Geoscience Australia
Mr Glenn Hurry	Australian Fisheries Management Authority
Dr Glen Hyndes	Edith Cowan University
Prof. Greg Ivey	University of Western Australia
Mr Dave Johnson	Australian Fisheries Management Authority
Dr Di Jones	WA Museum
Dr John Keesing	CSIRO, Marine & Atmospheric Research
Dr Kim Klaka	Curtin University of Technology
Prof. Paul Lavery	Edith Cowan University
Ms I-Lyn Loo	WA Office of Climate Change
Mr Eric Lumsden	WA Department of Planning and Infrastructure
Mr Brett McCallum	Pearl Producers Association
Mr Mark McCallum	Australian Petroleum Production & Exploration Association Ltd (APPEA)
Dr Bill de la Mare	CSIRO Wealth from Oceans National Research Flagship
Ms Loisette Marsh	WA Museum
Dr Ray Masini	WA Department of Environment and Conservation
Dr Anne Mathews	WA Office of Climate Change
Prof. Gary Meyers	Integrated Marine Observing System (IMOS)
Dr Steve Newman	WA Department of Fisheries
Ms Anne Nolan	WA Department of Industry and Resources
Mr Greg Oliver	INPEX Browse Ltd
Ms Bernadette O'Neil	Department of the Environment, Water, Heritage and the Arts
Mr Duncan Ord	WA Department of Industry & Resources/ Northern Development Taskforce
Prof. Chari Pattiaratchi	University of Western Australia
Dr Jim Peacock	Chief Scientist, Commonwealth Government
Dr Ian Poiner	Australian Institute of Marine Science (AIMS)

Dr Chris Simpson	WA Department of Environment and Conservation
Ms Shirley Slack-Smith	WA Museum
Dr Luke Smith	Woodside Energy Ltd
Dr Peter Southgate	Geoscience Australia
Dr Marcia Taylor	Edith Cowan University
Dr Paul Vogel	WA Environmental Protection Authority
Mr Steve Waller	WA Office of Climate Change
Dr Kelly Waples	WA Department of Environment and Conservation
Dr Kate Wilson	CSIRO Wealth from Oceans National Research Flagship

WAMSI Governing Board

Dr Peter Rogers	Chairman, WAMSI
Dr Ian Poiner	Chief Executive Officer, Australian Institute of Marine Science
Mr Keiran McNamara	Director General, Department of Environment and Conservation
Dr Greg Ayers	Chief CSIRO Marine and Atmospheric Research
Mr Charles Thorn	Associate Director, Research and Development, Curtin University of Technology
Mr Peter Millington	Chief Executive Officer, Department of Fisheries Western Australia
Prof Alistar Robertson	Pro Vice-Chancellor (Research Initiatives), The University of Western Australia
Dr Diana Jones	Acting Director, Western Australian Museum
Dr Steve Blake	(Non-voting Member) Chief Executive Officer WAMSI

WAMSI Strategic Projects Committee

Dr Bernard Bowen	Chairman
Dr Peter Rogers	Chairman, WAMSI Board
Dr Steve Blake	WAMSI Chief Executive Officer
Ms Linda McGowan	WAMSI Executive Officer
Keiran McNamara	Director General, WA Department of Environment and Conservation
Dr Greg Ayers	Chief, CSIRO Marine and Atmospheric Research
Dr Ian Poiner	Chief Executive Officer, Australian Institute of Marine Science

WAMSI Headquarters

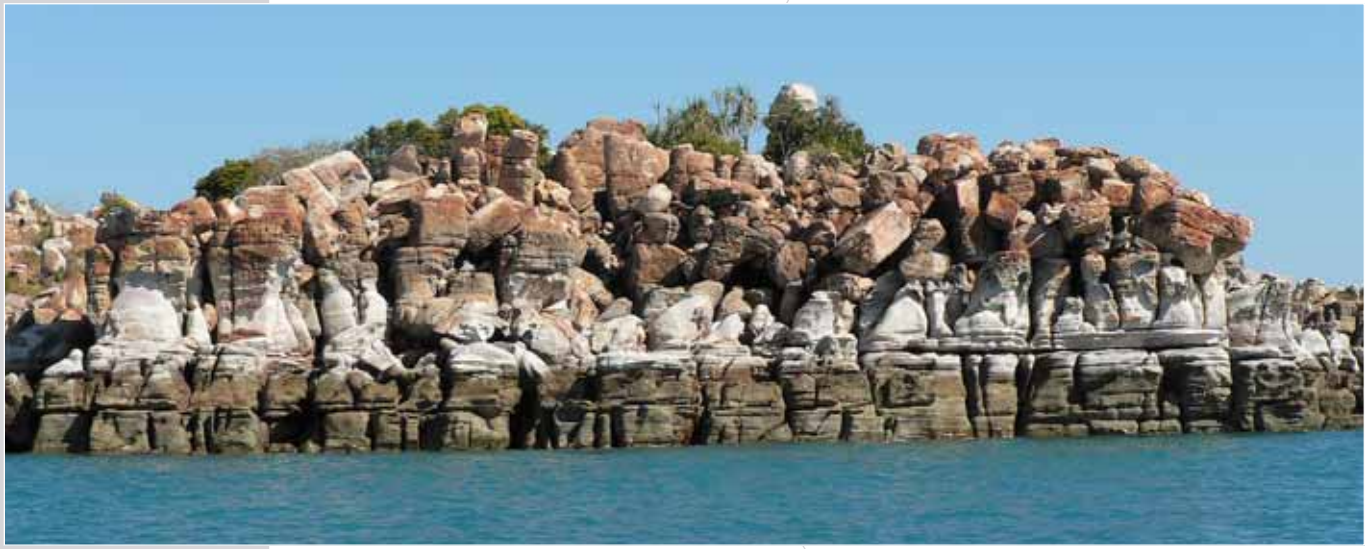
Dr Peter Rogers	Chairman, WAMSI Board
Dr Steve Blake	WAMSI Chief Executive Officer
Ms Linda McGowan	WAMSI Executive Officer
Ms Sue McKenna	WAMSI Communications Officer
Ms Lynne Stephenson	Personal Assistant to the Chief Executive Officer

Report Production Support

Leith Finnie/Julie Taylor	Par Excellence
Alison Blackwell	Ali B Design
Sue McKenna	WAMSI
Lynne Stephenson	WAMSI

Figure Reproduction Permissions

Geoscience Australia



western australian
marine science institution

Further information

Western Australian Marine Science Institution (WAMSI)
WAMSI Headquarters
Botany and Biology Building MO95
The University of Western Australia
35 Stirling Highway, Crawley WA 6009

P **+61 8 6488 4572** F +61 8 6488 4575

www.wamsi.org.au

003Aug08