



Australian Government



AUSTRALIAN INSTITUTE
OF MARINE SCIENCE

Research Plan

2011-2015

AIMS: Australia's tropical marine research agency.

The research described herein is based on early analyses of complex datasets and should not be considered definitive in all cases. Institutions or individuals interested in all consequences or applications of AIMS research are invited to contact the CEO at the Townsville address given below. Those wishing to discuss matters relating specifically to the material outlined in this publication should contact the AIMS Research Office by telephone on 07 4753 4444 or reception@aims.gov.au.

The Research Plan is reviewed during the course of the funding cycle to ensure that our efforts and resources are effectively targeted toward high quality outcomes for stakeholders. Please check on-line for any recent updates to this document, along with a range of other information about the Institute, at www.aims.gov.au.

For additional copies of this Research Plan, please telephone the Institute on 07 4753 4444, write to us at our Townsville address.

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Foreword

Australia is a nation that values and benefits significantly from its vast marine estate. The national value of production across marine-based industries (e.g. oil and gas exploration and extraction, tourism, fishing, boatbuilding, shipping, ports) was \$42.3 billion in 2009-10 — a major contribution to Gross Domestic Product, employment and infrastructure at national and regional levels ¹.

The majority (>85%) of our population lives within 50 km of the ocean and for many Australians “the coast” — islands, beaches, bays and estuaries, water sports and seafood — are integral parts of the national identity. As our population increases, associated industrial activity continues to expand along the coastal fringe and bulk commodity ports grow to service expanding resource-based export industries, the marine estate becomes an ever more vital national asset. Efficient utilization and wise management of this asset is therefore critically important to the national interest.

Our ability to reap the economic benefits on offer while maintaining marine ecosystem health and services requires improved understanding of the status of these ecosystems and their resilience to the growing (and cumulative) pressures they face. **Early investment** in an enhanced evidence base allows policy makers and environmental managers to more effectively manage risks and thereby streamline regulatory approval processes. This in turn provides marine industries with a higher degree of operating certainty. Given the scale of development and the growing impact of global change on the marine environment, advances in research leading to improved policy and regulation over the next decade will be crucial to ensure the wellbeing of our magnificent marine estate for generations to come.

This is particularly true for Australia’s tropical coasts and continental shelf waters: from Ningaloo Reef and the oceanic shoals of the Timor Sea in the Indian Ocean, through the shallow Arafura Sea, and along the Pacific coast and our iconic Great Barrier Reef. These ecosystems are of global significance for their biodiversity and conservation values. They are also incredibly rich in natural resources and

¹ The AIMS Index of Marine Industry, 2010

increasingly important for the oil and gas (Great Barrier Reef excepted), shipping, ecotourism, recreational fishing, commercial fishing and aquaculture industries.

Established in 1972, the Australian Institute of Marine Science (AIMS) was one of the first marine science agencies to study the Great Barrier Reef. Over the last 40 years, our wide-ranging program of research and strategic investments in broad scale monitoring and coastal ecology has provided AIMS with unparalleled insights into the suite of changes that have occurred, and continue to occur, in this complex ecosystem. While we continue to work on the Great Barrier Reef, the Institute's remit, research focus and geographic horizons, have grown significantly over the last twenty years, and AIMS is now well established as "Australia's tropical marine research agency". Our unique capacity to investigate topics ranging from microbiology to broad-scale ecology, utilising a modern research fleet and highly specialised facilities, world-renown staff and well developed national and international partnerships, has secured the Institute's position as a global leader in tropical marine science.

This Research Plan outlines the Institute's priorities for the next four years. Through active engagement with our stakeholders across government and industry, our objective is to continue our drive towards scientific excellence while ensuring that the foci of AIMS multidisciplinary science capability, infrastructure and research investment remain relevant and committed to national needs and aspirations.

Over the next four years, AIMS will:

- Deliver excellent science in each of the Key Research Areas identified in the Research Plan and work with our partners in industry and government to ensure delivery of the priority outcomes;
- Maintain our ranking in the top 1% of research institutions in the world in the fields of Environment and Ecology, and Plant and Animal Science;
- Continue to invest in exploration of the poorly-understood coastal and continental shelf ecosystems of north and north-western Australia;
- Deploy our multi-disciplinary science capability to examine cumulative impacts of anthropogenic influences on tropical marine systems, at scales ranging from local to regional;
- Increase investment in the analysis and integration of data collected over the last 40 years, and the development of dynamic and spatially-explicit models for use in conservation of biodiversity, climate change impact assessment and evaluation of climate adaptation, and environmental management strategies for coastal development and coastal water quality; and
- Work with the Australian marine science community to lead development of a national strategy for marine science capability and play a significant role in building national capability through post-graduate training partnerships with leading universities and investment in a vibrant post-doctoral program.

A particularly exciting development at AIMS over this quadrennium will be the commissioning of SeaSim, our new \$35 million tropical sea simulator, that will allow complex experiments to vary a large suite of environmental variables (e.g. temperature, light, CO₂, sediment loads, nutrients, etc.) and at the same time discover compounding effects among potential stresses on tropical organisms. SeaSim will support a number

of the AIMS research teams and their collaborators as they examine the effects of environmental variability and perturbation that are often critical unknowns in our estimation of the impacts of climate change and industrial development.

We recommend the Research Plan as a window into AIMS, and invite anyone interested in the results of the research and/or opportunities for collaboration to make contact with our science leaders.



Wayne Osborn
Chair, AIMS Council



John Gunn
AIMS Chief Executive Officer

Contents

Foreword	iii
About AIMS	1
Strategic Directions underlying this Research Plan	3
Supporting the National Research Priority goals.	7
AIMS as part of the National Innovation System	9
Operating Strategy	11
Key Result Areas to be delivered through the Tropical Marine Biodiversity Team	19
Key Result Areas to be delivered through the Water Quality & Ecosystem Health Team	35
Key Result Areas to be delivered through the Climate Change & Ocean Acidification Team	43
Key Result Areas to be delivered through the Marine Microbes & Symbioses Team	49
Appendix 1. National Research Priorities and Goals	55
Appendix 2. National Innovation Priorities	59
Appendix 3. Acronyms and Abbreviations	61



A massive fan coral juts out from the reef. Image: Eric Matson.

About AIMS

The Australian Institute of Marine Science (AIMS) is Australia's tropical marine research agency established by a parliamentary Act of the Australian Government (*Australian Institute of Marine Science Act 1972*). The Institute's first facility was established in Townsville in recognition of the importance of the Great Barrier Reef to Australia. Today AIMS operates from additional bases in Perth and Darwin to support our research across northern Australia, spanning two oceans and three regional seas.

AIMS mission is to *generate and transfer knowledge to support the sustainable use and protection of the marine environment through innovative, world-class scientific and technological research*. After 40 years, the Institute is known internationally for the quality of its research into tropical marine environments and their living aquatic resources.

To do this, AIMS pursues strategic basic and applied research into marine life systems from microbes to whole-of-ecosystems, including fundamental knowledge about the processes that sustain them; monitors condition and trends in the marine environment; and develops enabling technology across a broad spectrum from molecular sciences to ocean technologies.

The products of our research are designed to be used by others with target audiences including governments, marine policy officers, natural resource managers, environmental regulators, industry users, NGOs, scientific peers and the Australian public.

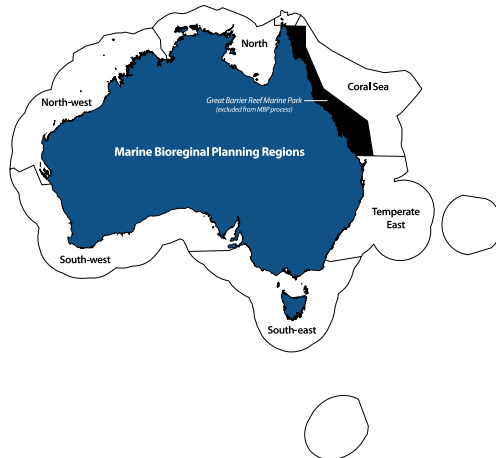
AUSTRALIA'S TROPICAL MARINE DOMAIN

More than 70% of Australia's territory is under water and almost 40% of our Exclusive Economic Zone (EEZ) lies north of the Tropic of Capricorn, representing 4 million km² of ocean territory. Today, over three billion people live in the tropical zone world-wide and this will double by 2060. In Australia, less than two million people reside permanently in the tropics, which is less than the annual number of tourists. Besides marine tourism, however, Australia's tropical oceans and seas are the source of significant national wealth from offshore oil and gas, ports and shipping, aquaculture, and fishing.

Despite this, much of Australia's tropical ocean territory remains inadequately surveyed and rapid development, particularly in the coastal zone, poses significant risks to environmental quality and the sustainable use of living marine resources.

Australia's modern economy was built from land-based industries (e.g. minerals, grazing, agriculture, forestry) for most of the last 200 years. In some instances, ecosystems have been put under too much pressure resulting in well-known environmental and societal problems like deforestation, soil erosion, salination, pollution, and over-allocated water. As we have concentrated our population along the coastal strip, urban corridors have alienated natural habitats, polluted waterways, and destroyed many ecological goods and services. As we became efficient at harvesting marine resources, multiple stocks had to be damaged before we understood the potentially destructive power of fishing and the limits on fish production set by oceanic drivers.

As Australia has debated the limits to growth and declared environmental sustainability to be a National Priority, there have been poignant reminders of how difficult and expensive it is to restore ecological balance by repair of terrestrial and freshwater ecosystems. On the land, we are guided to this conclusion by knowledge and vast amounts of information accumulated over two centuries. In the ocean, without the same learning experience and confronted by the greater cost of observation, we are often forced to take a more precautionary approach or else make decisions with inadequate knowledge. While this is true for most of the marine domain, it is especially true for the tropical seas that support the mega-marine biodiversity of coral reefs and the high productivity of mangroves and seagrasses.



The creation of AIMS, just 40 years ago, was an acknowledgement of the importance and iconic status of the Great Barrier Reef (GBR). Today, the GBR is no less important to the AIMS mission but, just as we have learned that it is not possible to protect the GBR without understanding both coastal and oceanic processes, we have also learned that Australia's tropical seas contain many other precious regional marine assets no less worthy of attention and all requiring similar strategic knowledge.

Strategic Directions underlying this Research Plan

AIMS delivers world-class marine science in areas of high priority for Australia and regional stakeholders. Our research supports marine policy, evidence-based decisions, and regional industry development by providing independent advice and essential knowledge about tropical marine ecosystems. We work closely with stakeholders and research-users to understand their needs in order to identify the most relevant research and to ensure the uptake of new knowledge.

Our new Research Plan, which extends from July 2011 to July 2015, was based on many inputs including an external review² by an international science panel of the 2007-11 Research Plan and consideration of the research priorities declared by key research users³. The result is a Plan that delivers to the National Research Priorities, the National Innovation Priorities, and regional stakeholder issues by merging ongoing and new elements into a portfolio built on our current capabilities to deliver science of high quality and significant impact.

Three broad strategic directions, reviewed and confirmed in 2010, describe the intent of our research:

- understanding tropical marine ecosystems and processes;
- forecasting responses of tropical marine systems to global changes; and
- supporting sustainable development of tropical marine-based industries.

In addition, AIMS research will be characterised by both technological and scientific innovation.

² The AIMS Science Review (2007-11 Quadrennium) is available for download at: <http://www.aims.gov.au/docs/publications/research-plan.html>

³ Example at http://www.gbrmpa.gov.au/corp_site/info_services/science_management/research_priorities/database/

Our research over the next four years will deliver new knowledge in ten Key Result Areas (KRAs):

- 1. New frontiers in tropical marine biodiversity
- 2. Baseline knowledge and monitoring for management
- 3. Patterns and processes in tropical marine biodiversity
- 4. Tropical aquaculture
- 5. Human impacts on water quality
- 6. Shelf-scale pelagic ecosystem processes
- 7. Australia's tropical seas - past, present and future
- 8. Resilience and vulnerability of coral reefs in a high-CO₂ world
- 9. Reef symbioses in a changing ocean
- 10. Harmful organisms

The outputs comprising these KRAs will be delivered through the efforts of four Research Teams:

- 1. Tropical Marine Biodiversity
- 2. Water Quality and Ecosystem Health
- 3. Climate Change and Ocean Acidification
- 4. Marine Microbes and Symbioses

The goals (Outputs/Outcomes) of each KRA will be the focus of our performance reporting systems.

The relationships between the AIMS Strategic Directions, Key Result Areas and Research Teams are illustrated in the following table. In a modification of previous arrangements, major infrastructure for research will be managed by a new team in the Research Directorate to maximise operational efficiencies and equity of access.

	Strategic Direction 1	Strategic Direction 2	Strategic Direction 3		
Key Result Area	<i>Understanding tropical marine ecosystems and processes</i>	<i>Forecasting responses of tropical marine systems to global changes</i>	<i>Supporting sustainable development of tropical marine based industries</i>	<i>Technology Innovation</i>	Team delivering research outcomes
New frontiers in tropical marine biodiversity	✓		✓	✓	Tropical Marine Biodiversity
Baseline knowledge and monitoring for management	✓	✓	✓	✓	
Patterns and processes in tropical marine biodiversity	✓	✓	✓	✓	
Tropical aquaculture	✓		✓	✓	
Human impacts on water quality	✓	✓	✓	✓	Water Quality and Ecosystem Health
Shelf-scale pelagic ecosystem processes	✓	✓	✓	✓	
Australia's tropical seas - past, present and future	✓	✓		✓	Climate Change and Ocean Acidification
Resilience and vulnerability of coral reefs in a high-CO ₂ world	✓	✓	✓	✓	
Reef symbioses in a changing ocean	✓	✓	✓	✓	Marine Microbes and Symbioses
Harmful organisms	✓	✓	✓	✓	
Ocean Observing	✓	✓	✓	✓	Research Infrastructure
Science Laboratories	✓	✓	✓		
Archival collections	✓	✓	✓	✓	
eScience	✓	✓	✓	✓	
Experimental Seawater Facilities	✓	✓	✓	✓	



Close up of *Acropora* polyps. Image: AIMS Long-term Monitoring Team.



Supporting the National Research Priority goals

AIMS mission aligns strongly with the National Research Priorities (see Appendix 1). The majority of our research supports the National Priorities of achieving 'An Environmentally Sustainable Australia' and/or developing 'Frontier Technologies for Building and Transforming Australian Industries'. The strength of the match is shown as highly relevant (☑☑☑), very relevant (☑☑) or relevant (☑).

National Priority and relevant goals										
		An Environmentally Sustainable Australia				Frontier Technologies for Building and Transforming Australian Industries				
		A1 — Water a critical resource	A2 — Transforming existing industries	A5 — Sustainable use of Australia's biodiversity	A7 — Responding to climate change and variability	C1 — Breakthrough Science	C2 — Frontier technologies	C4 — Smart information use		
AIMS Key Results Area	New frontiers in tropical marine biodiversity			✓✓✓	✓				Tropical Marine Biodiversity	Research Team
	Baseline knowledge and monitoring for management			✓✓✓	✓✓			✓✓		
	Patterns and processes in tropical marine biodiversity		✓	✓✓✓	✓			✓		
	Tropical aquaculture		✓✓✓	✓✓✓	✓✓		✓			
	Human impacts on water quality	✓	✓✓	✓✓✓	✓✓				Water Quality and Ecosystem Health	
	Shelf-scale pelagic ecosystem processes		✓		✓✓✓	✓	✓			
	Australia's tropical seas - past, present and future	✓			✓✓✓			✓	Climate Change and Ocean Acidification	
	Resilience and vulnerability of coral reefs in a high-CO ₂ world		✓		✓✓✓			✓✓		
	Reef symbioses in a changing ocean				✓✓✓	✓✓✓	✓✓✓		Marine Microbes and Symbioses	
	Harmful organisms			✓	✓✓✓	✓		✓		
Research Infrastructure	Ocean Observing	✓	✓✓	✓✓✓	✓✓✓		✓	✓✓✓		
	Science Laboratories	✓	✓✓			✓✓✓	✓✓✓			
	Archival collections			✓✓✓	✓✓					
	eScience		✓✓	✓✓✓	✓✓	✓✓✓		✓✓✓		
	Experimental Seawater Facilities	✓	✓✓	✓✓✓	✓✓✓	✓✓	✓✓			



AIMS as part of the National Innovation System

AIMS delivers a substantial portion of its science through joint ventures, strategic alliances, and collaborations; all research models that require co-investment. Cost sharing with willing and suitable partners increases the return on appropriation dollars received from the Australian Government. More importantly, it increases critical mass and broadens the skill base available to address complex questions about the sustainable use and protection of marine resources. As such, AIMS has an integral role within the National Innovation System.

Our current research builds on many years of sustained research effort and discovery. Some of our datasets now extend across decades and our footprint extends across the full range of tropical marine environments in Australia as well as selected locations outside Australia. From the skeletal records of massive corals, we have been able to track climate variation and other environmental change in the tropical seas around Australia throughout the entire history of European colonisation of the continent. In recent times, our ability to monitor the marine environment has been transformed by technologies enabling a greater geographic spread, higher sampling rates, and real-time data streams. We are not alone in this, and acknowledge the benefit of being part of Australia's Integrated Marine Observing System (IMOS: <http://imos.org.au/>) established with support of the Australian Government's National Research Infrastructure Strategy (NCRIS).

IMOS involves cooperation among many organisations and became operational at the start of the 2007-11 Quadrennium. Currently, AIMS deploys or supports infrastructure from 9 of the 11 capability areas in IMOS and we acknowledge the profound acceleration of learning offered by the many new capabilities: the first wireless sensor networks on coral reefs; robotic gliders in the Coral Sea replacing research vessels; autonomous underwater vehicles extending our capacity to monitor change in depths hostile to divers; arrays of acoustic receivers that allow us to track mobile animals; automatic samplers on tropical research vessels; quality

data streams from the coastal seas about variations in temperature, salinity, water quality, and ocean acidity collected from space and/or oceanographic moorings and permanent reference sites. All of these data streams provide context for our current and future observations on life in the sea and will improve our ability to model complex ecosystems and forecast their likely responses to current pressures, alternative management scenarios, and future climate states. In turn, this will allow us to shift more resources away from conventional monitoring to frontier science including complex problems of ecosystem behaviour, environmental change and adaptation, deepwater communities, and processes in the microbial world that control biogeochemical cycles, and disease.

The exposure of our science to independent external review at the end of each Research Plan (see Operating Strategy) ensures that AIMS maintains focus on both the quality of our science and its impact on research users. This awareness is passed through to the next generation of researchers because AIMS commits significant resources to training research students and includes many early career researchers in its research program. This brings us into close collaboration with many Australian and overseas universities, exemplified by collaborative research agreements with the Australian National University, Charles Darwin University, James Cook University, the University of Tasmania, and the University of Western Australia.

All of this allows us to deliver strongly to several of the National Innovation Priorities (Appendix 2).



Retrieving equipment at South Alligator River, Northern Territory. Image: Steve Clarke.



Operating Strategy

The strength of AIMS is an integrated, multidisciplinary science program driven by world-class scientists supported by modern infrastructure capable of tackling complex problems of tropical marine science including some requiring long-term, large-scale data collection, synthesis, and application. We have the expertise and the capability to explore and understand this domain from molecules to ecosystems.

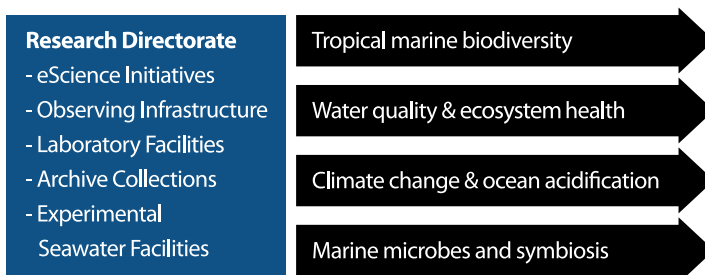
This Research Plan is underpinned by people, infrastructure, relationships with others, and process.

FOUNDATION 1: PEOPLE AND SKILLS

AIMS employs directly about 200 people and contracts essential services (e.g. vessel crews, maintenance, security, and canteen) from another few dozen. In addition, the Institute funds about 20 early career researchers (some employed by University partners – see Foundation 3) and provides facilities for about 50 significant others (PhD students and visiting scientists) across its three sites. This mixed staffing model reflects the Institute's multiple responsibilities for delivering solution science (to short-term problems defined by societal needs), discovering new knowledge (to solve more complex problems referred by our stakeholders and often requiring long-term data acquisition and/or strategic capacity building), and research training (to skill up the next generation of marine scientists).

In the period covered by the 2011-15 AIMS Research Plan, our science staff will be managed in four research teams; each constructed around core expertise appropriate to solving problems in four generic and eponymous themes: Tropical Marine Biodiversity; Water Quality and Ecosystem Health; Climate Change and Ocean Acidification; Marine Microbes and Symbioses. The primary outputs expected from each team during the next four years are described by Key Result Areas, reflecting focus and current capability. This delivery model demands that disciplinary skills be shared across teams because many complex problems require multidisciplinary solutions. For example, a microbiologist in Team 4 (Marine Microbes and Symbioses) will have research objectives in Annual Work Plans that apply her skills in one or more KRA associated with another Team (all three are relevant). This arrangement, which stops short of a full matrix model (KRA cross-cutting the disciplinary base), reflects

the size of AIMS and requires close co-operation among the four Research Team Leaders. Fortunately, our organisational size allows a high level of internal communication, which is orchestrated and supported by a small Research Directorate that also manages major research infrastructure on behalf of all teams (see following).



FOUNDATION 2: RESEARCH INFRASTRUCTURE

AIMS has world-class scientific infrastructure, capacity for technology innovation, science collections, extensive historical databases and modern information technology systems.

The Institute operates from three land-based facilities: Townsville (Queensland), Darwin (Northern Territory), and Perth (Western Australia).

In Townsville, the AIMS headquarters at Cape Ferguson is a 12,500 m² complex with direct water access surrounded by marine reserve and National Park. Naturally biosecure, the site provides opportunities for research not possible in other locations. Our coastal location at the geographical centre of the western edge of the Great Barrier Reef enables fast transition from sea to modern laboratories featuring:

- Advanced chemical and microbiological laboratories, some accredited to Physical Containment Level 2. One of these is the Centre for Marine Microbiology and Genetics (CMMG), a facility partly funded by the Queensland Government Smart State Fund, which includes AQIS-certified seawater rooms for work with aquatic pathogens. Another is the Biomolecular Analysis Facility (BAF) which is an integrated suite of Nuclear Magnetic Resonance Spectrometers (300, 900 MHz) with LC-MS capability and a Fourier-Transform Mass Spectrometer; and
- A seawater reticulation system supplying 600,000 litres of treated seawater per day into a range of outdoor aquaria, aquaculture facilities and controlled environment rooms. In 2013, we will be commissioning the National Sea Simulator (inset below) which will deliver a new level of control over seawater temperature and chemistry and increase flow capacity up to 3 megalitres per day.

In Darwin, AIMS is a joint operator with the Australian National University of the Arafura-Timor Research Facility (ATRF), which is an office and laboratory complex, adjoining Charles Darwin University. In 2012, the ATRF will reopen after an expansion also funded by the Australian Government's Super Science Initiative with facilities that will support a new North Australian Marine Research Alliance (NAMRA) linking AIMS, ANU and CDU with agencies of the Northern Territory Government. The refurbished facility will include a new experimental seawater facility allowing controlled laboratory experiments of immediate relevance to

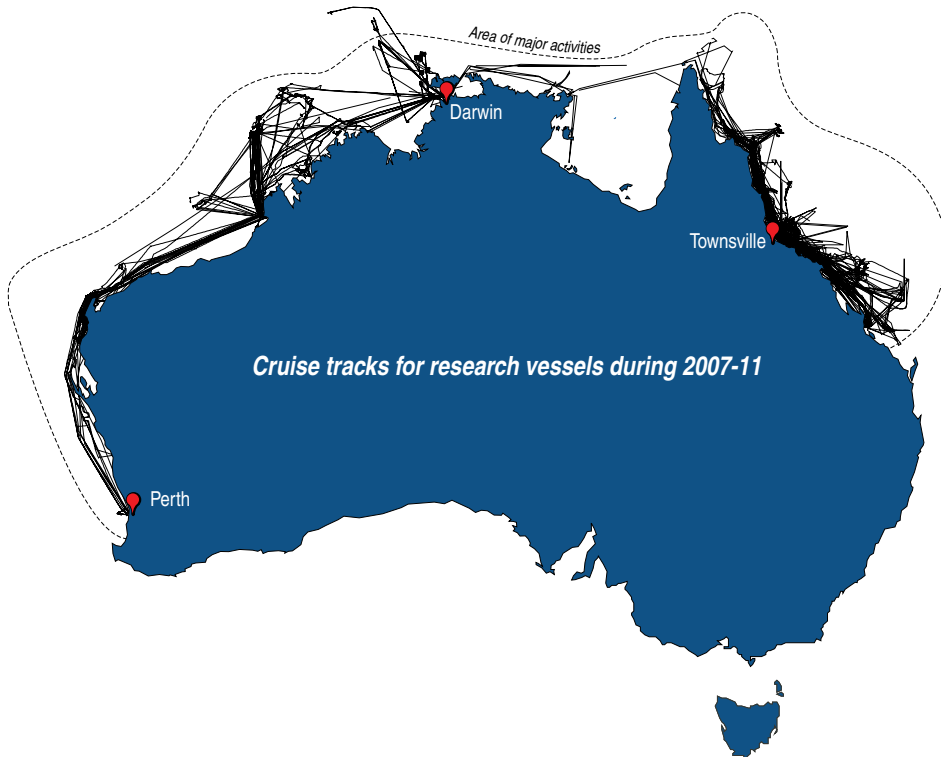


The \$35 million National Sea Simulator will provide precise control over temperature, acidity, salinity, sedimentation and contaminants in large volumes of seawater to allow Australian and international researchers to determine the impact of water quality on tropical marine organisms and ecosystems. Experiments in the SeaSim will reveal the potential of marine biota to adapt to climate change and assist in the development of mitigation strategies. *Funding for the National Sea Simulator was provided by the Australian Government through its Super Science Marine and Climate Initiative and the Education Investment Fund.*

Darwin Harbour. Other facilities include a stable-isotope mass spectrometer laboratory. In Perth, AIMS is a joint tenant of the Oceans Institute on the campus of the University of Western Australia. By the end of the Quadrennium, both partners together with CSIRO will move into a new Indian Ocean Marine Research Centre to be established on a nearby location. This will be a modern office and laboratory complex befitting an investment of more than \$50 million in the building, again with major support from the Commonwealth's Education Investment Fund. In addition, marine researchers in Perth will be provided with flow-through seawater facilities through a major refurbishment by the State Government of the Hillarys Laboratory, on a prime coastal site, once occupied by the WA Department of Fisheries.

AIMS on-ground infrastructure is supported by two coastal oceanographic research vessels, the 35 m RV *Solander* and the 24 m RV *Cape Ferguson*, each capable of operating throughout the Australian EEZ (Southern Ocean excepted). Both vessels have made international voyages to neighbouring countries and are capable of 24 hr operations supporting voyages lasting up to three weeks. Given their relative sizes and capacity (*Solander* - 12 scientists, *Ferguson* - 10 scientists), the larger vessel is currently operating from Broome to service science from Geraldton, WA, to the Gulf of Carpentaria, while the smaller vessel is home ported in Townsville to service the east coast from Gladstone,

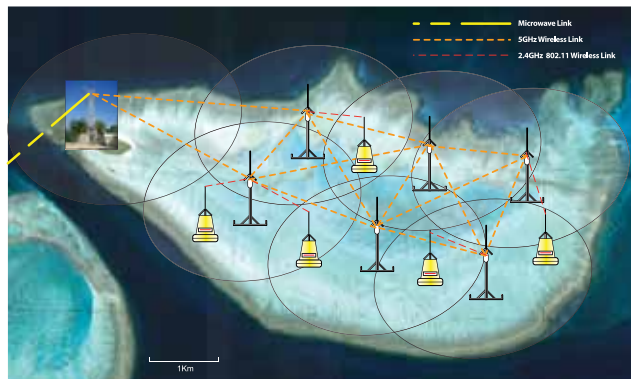
Queensland, to the Torres Strait. Both vessels are in very high demand and each typically spend at least 270 days per year each supporting scientists at sea.



The AIMS science program is supported by a light marine engineering facility in Townsville consisting of integrated workshops (electronics, fitting and turning, metals and plastics construction) providing a complete (design to prototype) service for developing and testing new technology. The mechanical workshop is provisioned with computer-controlled tools (lathe, milling machines) allowing precision machining of custom equipment and the combined services has developed some very innovative technology (e.g. lasers to measure *in situ* coral growth, underwater respirometers, etc.).

The Institute holds several collections of national significance, including the AIMS Bioresources Library and the Australian Coral Core Archive. These collections are valuable resources attracting international attention and often used by students and visiting scientists from other organisations.

The core business of AIMS is data acquisition and knowledge transfer, which requires the transformation of information into meaning. The strengths of the AIMS science program include its ability to tackle complex problems requiring multidisciplinary solutions, long-term data collection, large-scale observations, or voluminous calculations (e.g. hydrodynamic modelling, bioinformatics). The management of data and information is therefore a critical capability and the Institute is well served by the AIMS Data Centre, which in turn is dependent on the modern computing infrastructure provided by the AIMS Information Technology Group. The latter provides mass storage, fast servers, and secure systems to sites and links AIMS scientists with each other and their collaborators via high-speed broadband through the AARNET backbone. Satellite services, including email, provide communications and real-time data links from the AIMS vessels as well as autonomous data streams from a growing number of environmental monitoring stations including weather stations, oceanographic buoys, and wireless sensor networks (inset below).



The World's first wireless sensor network over a coral reef was established by AIMS on Heron Reef in 2008 as part of the Integrated Marine Observing System (IMOS) infrastructure deployed on the Great Barrier Reef.

FOUNDATION 3: RELATIONSHIPS

From its founding days, AIMS has been a collaborative organisation. This was driven partly by the lack of Australian tropical scientists in the seventies during the nascent days of coral reef science, partly by the geographical position of AIMS and James Cook University in Townsville providing a natural gateway to the Great Barrier Reef for overseas researchers, and partly by functions embedded in the AIMS Act (1972) which directs the Institute to assist others to carry out research and development in marine science and technology.

In addition to providing visiting scientists with facilities, the Institute has a proud history of training post graduates, initially via strong peer-to-peer relationships with academics from the Department of Marine Biology at James Cook University. In more recent times, this model has been formalised and extended to collaborative ventures with other institutional partners.

In 2003, the AIMS@JCU program was established with James Cook University (JCU) to support postdoctoral researchers and higher degree students from the University working at AIMS. In 2005, AIMS joined a partnership with JCU and others to form the ARC Centre of Excellence in Coral Reef Studies and continues to co-fund postdoctoral Fellows in the Centre's Research Program.

In 2004, AIMS commenced building the Arafura and Timor Seas Research Facility in Darwin on land owned by the Australian National University adjacent to Charles Darwin University. In 2011, the three organisations together with the Northern Territory Government formed the North Australia Marine Research Alliance (NAMRA), which is a collaborative research agreement that will attract postdoctoral fellows and research students to work in the region. In addition, AIMS collaborates with scientists from Timor Leste and Indonesia through a regional partnership sponsored by the United Nations Development Program (UNDP) known as the Arafura and Timor Seas Experts Forum (ATSEF).

In 2007, AIMS relocated its staff in Western Australia on to the campus of the University of Western Australia (UWA) and shortly afterwards began co-funding joint positions. In 2008, the University aggregated its own marine scientists into an Oceans Institute and both parties relocated to a common building. As part of this closer relationship, AIMS and UWA created a research collaboration agreement (RCA) to select and jointly fund early career researchers. In 2010, the RCA was expanded to include CSIRO as a third partner in anticipation of all three organisations becoming co-tenants of the new Indian Ocean Marine Research Centre to be built in 2012-13.

FOUNDATION 4: PROCESS

AIMS uses two key performance indicators to set and evaluate its quadrennial research programs. These are science quality and research relevance.

The relevance of much of AIMS research is confirmed by external investment, which influences what we do. In other words, one measure of the value of AIMS research is the willingness of third parties to pay to access the research capabilities of the Institute. While this can be a commercial arrangement (i.e. providing AIMS services and expertise at full cost), more often it involves co-investment where the Institute is prepared to share the cost of research because of the intrinsic value of the research questions. This is the default model for public good research.

In the 2007-11 Quadrennium, a substantial portion of AIMS research was supported by funds from large public programs (e.g. Commonwealth Environmental Research Facility, Integrated Marine Observing System, Western Australian Marine Science Institution, etc.). In the previous Quadrennium, AIMS was a partner in multiple Co-operative Research Centres (CRC Reef, CRC Torres Strait) and, in this new one, the Institute will co-invest in three major Research Hubs (NERP Tropical Ecosystems, NERP Marine Biodiversity, NERP North Australia) funded as part of the National Environmental Research Program of the Australian Government. The common feature in all of these ventures is that they are partnerships between Governments, industries, NGOs (e.g. conservation, recreational fishing, and regional resource management networks) and research providers such as AIMS. By their nature, these public programs are inherently representative and deeply consultative so that research investments made in this atmosphere have a high probability of resulting in effective knowledge transfer to one or more research users.

AIMS will continue to place high priority on consulting with key stakeholders and working within research partnerships designed to service the needs of public and private sector users of scientific data and information. The key role of research-users in setting the priorities and approving the research programs of these public programs provides a more

direct knowledge transfer pathway and guarantees the relevance of each investment. In addition, these large programs have internal processes to monitor and evaluate science quality (strategic plan, milestone reports, annual review, annual work planning) as well as being subject to external audit at the conclusion of each funding period.⁴

Other co-investments in the AIMS research portfolio include contracts from Industry R&D schemes (e.g. Fisheries Research and Development Corporation), as well as research grants (as Partner Investigator) and individual Fellowships from schemes administered by the Australian Research Council. These funding schemes are highly competitive with success rates as low as 20%, which benchmarks the performance of AIMS scientists against the best academics from Australia's tertiary sector.

While co-investment (with the exception of individual awards based on academic excellence) has an opportunity cost through reduced flexibility, external revenue allows the Institute to have a research program that is at least 150% of the one that could be supported solely by the appropriations from the Australian Government. Of course, there is a ceiling to this leverage and the Institute therefore has internal processes (of prioritisation) to ensure that each new commitment provides an appropriate return on the co-investment of core funds (based on the metrics of quality and impact). This is a judgment call by AIMS senior management acting within the Policy framework set by AIMS Council that is always made without perfect knowledge of the opportunity cost. Consequently, the Institute's research portfolio is a dynamic balance that evolves over the time course of a Research Plan.

At the end of each Research Plan, the Institute validates its decisions by investing in an independent external review of its past performance that is undertaken by a panel of international disciplinary experts. This is additional to the independent review processes associated with major funding sources such as MTSRF and WAMSI. The Quadrennium Science Review provides a unique retrospective over the whole AIMS research portfolio, which also includes internal decisions around investing approximately 10% of the research income back into strategic appointments and emerging science.

The Quadrennium review considers quantitative measures of research quality such as publication metrics to assess the contributions of AIMS scientists to the international peer-reviewed literature. The latter show that AIMS consistently ranks in the top 1% of research institutions in the world for the fields of Environment and Ecology, and Plant and Animal Science.

The Quadrennium review also considers the impact of AIMS research on public policy or practice, industry assistance, or other examples of successful knowledge transfer to research users.

All of these sources of information are factored into the formation of each new Research Plan.

⁴ MTSRF external review of outcomes



An array of coral morphologies. Image: Ray Berkelmans.

Key Result Areas to be delivered through the *Tropical Marine Biodiversity* Team

- 1) New Frontiers in Tropical Marine Biodiversity**
- 2) Baseline Knowledge and Monitoring for Management**
- 3) Patterns and Processes in Tropical Marine Biodiversity**
- 4) Tropical Aquaculture**

Biodiversity has intrinsic environmental, economic and social values, as well as producing tangible ecological goods (e.g. fish catches) and services (e.g. nutrient cycling). Human activities designed to extract economic value from natural resources always carry some risk of unintended consequences that lower the capacity of the environment to sustain the level of resource exploitation, or compromise environmental resilience to other pressures such as climate change. The net result of cumulative multiple pressures can be a loss of invaluable ecosystem services including social amenity values.

The problem can take many forms. In the case of wild harvests, excessive take typically results in a vicious cycle where ever-increasing effort is applied to chase ever-diminishing returns with great potential to harm ecosystem integrity and resilience. While the science and management of harvesting wild populations is continually improving, demand for seafood is growing relentlessly and aquaculture is increasingly being used as the source of production. Aquaculture is particularly important for the food security and economies of neighbouring countries in the Coral Triangle of SE Asia but intensive production also has the potential to degrade coastal water quality or encourage overharvesting by using wild fish to feed captive animals. This has high potential to set up conflict with other industries, particularly marine tourism which requires high quality environmental experiences.

The challenge for managers and regulators is to balance competing interests so that the cumulative effect of multiple pressures produces no lasting damage and ecosystems retain their maximum natural resilience. This is a challenging task because it involves managing people and the difficulties are greatest in the most contestable spaces, especially the coastal zone with its myriad stakeholders.

Among managers and regulators, there is a strong desire that policy and decision making processes be based on evidence. As a science agency, AIMS seeks understanding of ecosystem structure and function at whole-of-system scales that can be converted to useful knowledge and transferred to research-users. The knowledge sought by the Tropical Marine Biodiversity Team will have direct relevance to the sustainable futures for key marine industries (fisheries, aquaculture, tourism, offshore oil and gas), and will be transferred to marine managers and regulators in Queensland, Western Australia, Northern Territory and the Australian Government. Through our participation in major research collaborations such as the National Environmental Research Program (NERP), the Western Australian Marine Science Institution (WAMSI), and the North Australian Marine Research Alliance (NAMRA), AIMS research will also be exposed to and shaped by a more inclusive group of stakeholders.

During the next four years, the Tropical Marine Biodiversity team will conduct scientific research designed to fill a number of existing knowledge gaps in four Key Result Areas.

KEY RESULT AREA 1. NEW FRONTIERS IN TROPICAL MARINE BIODIVERSITY

Synopsis: Projects that focus on the discovery and description of bioregions in remote or inadequately surveyed areas. Pioneering surveys in these areas will document the distribution and characteristics of major habitats and biological communities. The mapping and species characterisations will also result in the discovery of new biodiversity with key taxa (e.g. sponges) being curated in a biological repository intended to be a resource for the discovery of novel organic molecules by external screening programs.

Activities under this Key Result Area will result in two streams of research:

Project 1. Voyages of discovery

Australia's tropical coasts are fringed by broad continental shelves (less than 100 m deep), especially those facing the Arafura and Timor Seas, that encompass multiple Provincial Bioregions in the marine bioregional planning undertaken by the Australian Government⁵. Because of the vast size and remoteness of this domain, the majority of these bioregions remains inadequately surveyed although large areas are known to be rich in biological and energy resources.

The exception is the Great Barrier Reef, which extends along 2,300km of Queensland's northeast coast. While the World Heritage status and immense economic value of this unique ecosystem has justified a large amount of historical exploration and research, even here the most intense focus has been on the iconic coral reefs that comprise just 6% of the multi-use Marine Park. Five years ago, four agencies (AIMS, CSIRO, Queensland Museum, and Queensland Fisheries) pooled resources in the Great Barrier Reef Seabed Biodiversity Project to map over 200,000 km² of shallow seafloor habitats but 30% of the Marine Park (below 200m) still remains largely unexplored.

AIMS has a unique mandate and resources that enable it to explore and describe Australia's tropical marine environments but the enormity of this task requires a high level of prioritisation. Compared with the Great Barrier Reef, the northern waters of Western Australia represent much larger knowledge gaps despite the need for such information during the rapid expansion of the offshore oil and gas sector. Since her maiden voyage in

⁵ <http://www.environment.gov.au/coasts/mbp/index.html>



2008, the Institute's flagship vessel (RV *Solander*) has been kept almost continually at sea supporting research in remote locations between Exmouth and Darwin.

The *Solander's* discovery missions in the last three years have included: mapping 75% of the deepwater sections of the Ningaloo Marine Park in Western Australia; exploring and mapping flanking habitats around Montgomery Reef (Australia's largest inshore reef) off the Kimberley Coast; mapping and characterising deep water benthic communities at the oceanic Scott Reef in the Indian Ocean; surveying environments associated with new releases of petroleum acreage in the Joseph Bonaparte Gulf; surveying shallow banks and shoals along the edge of the Sahul Shelf; crossing the Timor Sea to make some of the very first underwater surveys of the south coast of Timor Leste with scientists on board from Timor and Indonesia.

Three of the Australian voyages of discovery have been conducted as a partnership with scientific staff from Geoscience Australia, who brought new capability in multi-beam sonar mapping of bathymetry and other geoscience technology including sub-bottom seismic profiling and sediment analysis. These extended capabilities have complemented our skills in ecological habitat characterisation using towed cameras and biodiversity sampling. The combination has produced more complete benthic characterisations and better understanding of ecological patterns, which are shaped as much by recent geological processes as by modern oceanography. These multidisciplinary collaborations are planned to continue annually.

While these voyages have produced timely and useful results, the effort to date falls a long way short of our ambition to build adequate regional-scale maps of habitats and biodiversity values for these large marine domains as the first step towards constructing regional risk assessments and predictive risk models incorporating ecosystem function and response. Consequently, we forecast that the RV *Solander* will continue throughout the term of this Research Plan to make similar voyages of discovery along the northwest margin to fill in the largest blanks on this canvas. We also anticipate expeditions to the shelf waters of the Northern Territory, east of Darwin, particularly around Gove and the western Gulf of Carpentaria. On the east coast, we await the launch of the new Marine National Facility vessel RV *Investigator* to support long-planned collaborative research with CSIRO in the Coral Sea.

Project 2. Bioresources Library

Biodiscovery is the search for bioactive molecules produced naturally by plants, animals, fungi or microorganisms that may have a novel application in medicinal or industrial chemistry (e.g. pesticides). AIMS began concerted sampling of Australia's mega-marine biodiversity in 1993 to build the foundation of the current Bioresources Library (BRL), which is curated specifically for biodiscovery and now holds information and samples from about 20,000 macro- and micro-organisms. Following a refocus of effort for the last Research Plan, our strategy shifted to maintaining this archival collection, adding to it incrementally through the incorporation of legacy collections and piggyback operations on voyages of discovery, and connecting the growing collection with external providers of high-throughput screening.

In the last Research Plan, many of the voyages listed above generated new biological material, most of which has been deposited into the AIMS BRL, with the exception of material from south-west WA and Ningaloo Reef, which has been deposited into a companion library (the Western Australian Marine Bioresources Library, WAMBL), which is part of the WA Museum. The WA Institute of Medical Research has been an early user of materials from WAMBL, and the State of Western Australia is in the process of developing new legislation to facilitate commercial biodiscovery linked to WAMBL.

In 2010, AIMS formed a new collaboration with the University of the Sunshine Coast for the revival and fermentation of selected marine microbes from the BRL, and negotiated issues of legal ownership to the biodiversity samples collected by the GBR Seabed Biodiversity Project so that these materials can be added to the Library in 2011-12. As a foundation partner, AIMS also made the first significant transfer of open access samples into the Queensland Compound Library (QCL) which is a joint initiative of Griffith University and the Queensland Government supported by the Smart State Innovation Fund. Currently, AIMS samples constitute the second-largest collection of open access samples in the QCL. Benefit-sharing agreements between AIMS and the Commonwealth, and AIMS and the Queensland Government provide legal certainty over these samples, which is an important consideration for industry partners.

Now that these arrangements are in place, the collection and deposit of raw materials into the AIMS BRL or, if appropriate, WAMBL will be a routine feature of future voyages of discovery in State and Commonwealth waters from northern Australia. New samples from the BRL will be submitted to the QCL in annual batches where they will remain available for formatting and dispatch to third parties for screening. AIMS will facilitate access to these samples, through the QCL and mechanisms such as the AIMS agreement with the US National Cancer Institute. Importantly, the BRL will also facilitate timely resupply of selected bioresources in order to support the development of leads by third parties. The first example concerns the resupply of Chondropsin molecules, which are a drug candidate discovered from sponges from the AIMS BRL.

Planned Outputs

- Maps of bathymetry, benthic habitats and ecological communities in poorly-studied areas;
- Predictive maps of community and species distributions based on physical surrogates;
- Identification of unique (e.g. biodiversity hotspots) or sensitive areas or ecological communities;
- Discovering new species including cryptic species revealed by genetic signatures;
- New material added to the AIMS BRL or, if appropriate, WAMBL;
- Fractionated extracts from suitable samples made available for biodiscovery in the QCL; and
- Biodiscovery 'hits' re-supplied to support lead development.

Desired Outcomes

- Conservation value and risk assessments at regional scales provided to industry and regulators;
- Transfer of knowledge supporting evidence-based management decisions or policy development;

- Improved knowledge base supporting the National Marine Bioregions Programs;
- Enhanced biodiversity collections in the museums of NT and WA; and
- AIMS BRL provides samples from which novel molecules are developed as drug candidates.

Key Research-users

Oil and gas industry; Environment Agencies (State, Territory, Federal); Industry Regulators; marine taxonomists; biodiscovery programs; translational science programs.

Initial Focus of Plan

- Extend biodiversity surveys of marginal banks and shoals along the Sahul Shelf;
- Survey additional sites in the Joseph Bonaparte Gulf (with Geoscience Australia);
- Survey strategic sections of the Kimberley Coast as part of the WAMSI research plan;
- Develop spatial models of marine biodiversity based on environmental drivers;
- Streamline procedures for accessioning materials into AIMS Bioresources Library;
- Enhance the flow of materials from the BRL to high-throughput screening facilities; and
- Re-supply lead metabolites (e.g. Chondropsins) to facilitate lead development.

Performance Measures

- Habitat and biodiversity maps for deeper parts of Ningaloo Marine Park;
- Habitat and biodiversity maps for South Scott Lagoon;
- Joint publications with Geoscience Australia on areas surveyed in Joseph Bonaparte Gulf;
- Joint publications with WA Museum on sponge communities from Ningaloo Reef;
- Use of AIMS data/outputs in bioregional plans, conservation measures, etc.; and
- Samples from the BRL being accessed by third party request.

KEY RESULT AREA 2. BASELINE KNOWLEDGE AND MONITORING FOR MANAGEMENT

Synopsis: Projects that focus on long-term data collection: e.g. continue long-term monitoring programs on east (Great Barrier Reef) and west (various locations) coasts of Australia, and implement a new program for Torres Strait communities. In addition to monitoring status and trend, AIMS will assess the performance of spatial management on biodiversity outcomes for the Great Barrier Reef Marine Park, and reassess the environmental impacts from two major marine incidents. We will also continue to synthesise and transfer new knowledge to research users, while enhancing our knowledge of apex fish predators, especially sharks.

Activities under this Key Result Area will result in two streams of research:

Project 1. Condition and trend of critical ecosystems

The Great Barrier Reef is a busy multiple-use marine park managed by the Great Barrier Reef Marine Park Authority (GBRMPA). Every year, the GBRMP generates billions of dollars and 50,000 jobs for the Australian economy from industries based around fishing, marine tourism, ports and shipping⁶. As a priceless asset built around core biodiversity values, the health of the GBR is a matter of national concern in Australia and its status as a World Heritage property raises international obligations. Since 2003, GBRMPA has measured its performance by seven Key Performance Indicators of which the first is "The level of hard

⁶ GBRMPA Outlook Report (2009)

coral cover at various sites along the Great Barrier Reef as assessed by the Australian Institute of Marine Science Long-term Monitoring Program"⁷.

On 1 July 2004, the GBR Zoning Plan (2003) came into effect and resulted in a large expansion of the area of the Marine Park closed to fishing (from 4.5% to 33.3%). As the single most significant change to the zoning since 1978, GBRMPA has articulated a strong need to know the impact of the change on reef biodiversity. In response, the AIMS Long-term Monitoring Program (LTMP) was co-opted from 2005–2006 to assess the impacts on a bi-annual basis of the new Zoning Plan on biodiversity of mid-shelf reefs from Cairns to Gladstone. These surveys will alternate with the broad-scale monitoring that has been in place since 1986.

Following an external review in 2006, the Australian Government passed legislation requiring GBRMPA to produce an Outlook Report every five years to identify pressures, current responses and consider the likely outlook for the reef. The first Outlook Report was published in 2009 and made full use of AIMS long-term data sets on biodiversity, water quality, and climate variability. The next Outlook Report is due in 2014 and will be an important vehicle for knowledge transfer of appropriate elements of the AIMS science program described in this research plan.

Co-incident with the start of the new Quadrennium, the Commonwealth Environmental Research Facilities (CERF) Program administered by the Federal environment department has been replaced by a new program rebadged as the National Environmental Research Program (NERP). The NERP will fund five national research hubs of which the largest, the NERP Tropical Ecosystems Hub, will deliver applied research valued at \$60 million over four years for the GBR, Torres Strait, and the rainforests of north Queensland. AIMS is one of four major research providers to this Hub along with CSIRO, James Cook University, and the University of Queensland.

As part of the NERP TE Hub, AIMS will work with the Land and Sea Management Unit (LSMU) of the Torres Strait Regional Authority (TSRA) to design and implement an appropriately-scaled version of the AIMS LTMP for monitoring the condition and trends of reefs and reef resources in the Torres Strait. Within the life of the Hub, this program will be transitioned from one of co-delivery to full responsibility by the LSMU and implemented by their Sea Rangers. This is not dissimilar to the role that AIMS played in WA during the last Research Plan, as part of WAMSI, to work with new staff in the WA Department of Environment and Conservation (DEC) to co-design and implement a shallow reef monitoring program for Ningaloo Reef that will be continued by DEC staff.

In WA, AIMS has been monitoring shallow fish and coral communities on Scott Reef since 1994 to understand natural variability and resilience on a very isolated oceanic reef. In the last Research Plan, the intensity of this surveillance was raised by orders of magnitude when the Browse Joint Venture Partners decided to move from retention to development phase to exploit the natural gas reservoirs lying adjacent to and underneath this reef complex. At the start of the last Quadrennium, AIMS monitored the impact on the shallow water fish and corals of the first seismic survey of a coral reef in Australia. Subsequently, as part of assisting Woodside Energy Ltd (representing the Browse Joint Venture partners) to prepare the EIS for government approval, AIMS delivered a multi-million dollar program

⁷ GBRMPA Annual Report 2007-08



(the Scott Reef Research Project) to map and monitor change in shallow and deep lagoon environments along with comprehensive physical oceanography of the region.

Now that the Scott Reef Research Project has been concluded successfully, AIMS will revert to a less intense model of regular monitoring but with coverage expanded from the historical focus on shallow fish and corals. This is due to our awareness of a diverse and rich community of benthic primary producers throughout the South Scott Lagoon in depths of 30-70 m that is potentially vulnerable to ocean warming. These depths are inaccessible by scientific divers so it is fortuitous that the last Quadrennium coincided with the major investment by the Australian Government in an Integrated Marine Observing System (IMOS) for Australia that was funded as part of the National Collaborative Research Infrastructure Strategy (NCRIS).

One of the research infrastructure projects supported by IMOS was the creation of a national Autonomous Underwater Vehicle (AUV) Facility at The University of Sydney operated by the Australian Centre for Field Robotics (ACFR). With IMOS funding, ACFR has been able to commit the AUV Sirius to repeat benthic surveys in at least a dozen national sites. The configuration of this robot is such that it produces photomontages of such fidelity and clarity that images from repeat missions can be accurately aligned allowing the detection of quite minor change.

In the last Quadrennium, the AUV Sirius was deployed in the South Scott Lagoon in 2009 and 2011 and this biannual pattern will continue into the future. From 2012, biannual surveys will be commenced in the rich sponge gardens found at the entrance to Exmouth Gulf. On the east coast, the robot was used in 2011 to resurvey 14 sites in the GBR Lagoon off Townsville that had rich seagrass in 30 m during the GBR Seabed Biodiversity Project (2005-06). In 2011, after the summer of extreme floods and the passage of severe TC Yasi through the area, these areas were devoid of all macroscopic life. Biannual surveys on these sites from 2013 will follow the recovery of the seagrass, which is an important food source for many animals including Green Turtles and dugongs. In 2012, a similar set of sites will be established on the continental shelf in the southern GBR between the Capricorn-Bunker reefs and the Port of Gladstone. In 2005-06, the Seabed Project showed that this is another area with high biomass of marine plants including seagrass, which is believed to be a signal of oceanic upwelling onto the continental shelf (a feature shared with the known intrusions of cold bottom water into the GBR Lagoon through Palm and Magnetic Passages off Townsville). It is unlikely to be coincidence that some of the richest trawl fisheries are located between Yeppoon and Fraser Island, which is a key reason for monitoring the health of the shelf communities, including deep seagrass, in this region.

In the last Quadrennium, AIMS responded to two major marine incidents. In April 2010, a foreign-flagged coal carrier, Shen Neng 1, ran aground on Douglas Shoal in the Capricorn-Bunker Group while transiting from Gladstone Port to the open sea. The ship remained on the shoal for nine days but shifted position on high tides so that it created an unusually broad swathe of physical damage to the substrate. In addition, there was a small oil spill from ruptured tanks with the potential to lose a major amount if the ship broke up as it was carrying a full fuel load in preparation for the trip to China. After tasking by the GBRMPA, AIMS mobilised the RV *Cape Ferguson* to take a scientific team to the area (48 hours steam from Townsville) arriving while the vessel was still aground. In this way, scientific assessments could begin as soon as the vessel was refloated.

AIMS deployed a multibeam sonar unit from James Cook University to map the area of damage, and then used its divers to collect photographic evidence and sediment samples from the damaged reef. Subsequent chemical analysis detected pollution by anti-fouling chemicals over a wide area of the reef top. The shoal will be revisited during the course of this Research Plan to determine whether there has been any detectable impact from this pollution.

In Western Australia, the West Atlas platform drill rig operated by PTTEP Australasia suffered a well head accident in August 2009 resulting in the uncontrolled discharge of oil and gas for 74 days to a section of the Timor Sea within 70 nm of Ashmore and Cartier Reefs. After four unsuccessful attempts, the well was plugged in November. In April 2010, AIMS made diver-based assessments on the two reefs and preliminary assessments of two submerged shoals (Vulcan, Barracouta Shoals) using remote cameras. A year later, the platform operator tasked the RV *Solander* with an extensive program to assess the status of reefs and shoals inside and outside the modeled dispersal plume. In addition, spat collectors were placed on the reefs for the duration of the coral spawning season to look for possible sublethal effects from any dissolved contaminants including the oil dispersants that were used extensively throughout the discharge period. Depending on the final outcome of these assessments, additional voyages to this region may be scheduled in the 2011-15 Quadrennium.

Project 2. Movements and habitat use by marine animals

In the last Quadrennium, AIMS continued research on the seasonal occurrence of migratory whale sharks off the Ningaloo Reef Tract, which includes ongoing population census using a combination of photographic records to identify individuals and genetic analyses of biopsy samples to identify lineage (breeding stock) structure. These studies were supported by expeditions to other rim sites in the Indian Ocean (Christmas Island, India, Djibouti, Seychelles) to create a co-operative network exchanging similar information and samples to track these ocean wanderers.

At a local scale, AIMS assisted the Australian Animal Tagging and Monitoring System (AATAMS) Facility of IMOS to deploy three cross-shelf lines of passive acoustic listening stations adjacent to Ningaloo Reef in early 2008. This regional network of receivers complements a dense local array established at Mangrove Bay by CSIRO in 2007 with the combined network referred to in IMOS as the Ningaloo Reef Ecosystem Tracking Array (NRETA). This array of receivers records detections from individual fish implanted with a small abdominal tag that emits a coded signal when it passes within a few hundred metres of a given receiver. With appropriate spacing of the listening posts, the movements of tagged animals can be tracked for the life of the transmitter (typically 18 months) and while the fish remains within detection range. Since 2008, a significant number and range of fish species have been tagged and released in the region with a focus on the larger reef fishes such as emperors, cods, sharks, and rays. While some species have shown remarkable site fidelity and small home ranges, others have shown seasonal migrations to spawning sites outside the Bay, while others have disappeared for almost a year before reappearing on the grid. This type of data was not available before the use of this new technology, and the new knowledge is crucial to proper assessment of the performance of existing sanctuary zones and to the design of future marine protected areas of adequate size to contain the large apex predators that are essential to maintaining a natural ecosystem.

Following the comprehensive rezoning of the GBR in 2004, the same type of information would be a valuable input to the next GBR Outlook Report due in 2014. As a result, AIMS will significantly lift the level of investment in this type of work on the east coast in the new Quadrennium. In 2011, this was enabled by infrastructure funds for 50 receivers from the AATAMS Facility, when IMOS was extended to 2013, and the award of a Tier 1 Future Fellowship to Dr Michelle Heupel who has joined AIMS to lead this research. With additional capital funds from the Institute, AIMS has established an array of 50 receivers covering Heron, One Tree, and Sykes Reefs in the Capricorn-Bunker Group, a small perimeter fence around the Scientific Research Zone encompassing the AIMS site in Bowling Green Bay, and an array around the Orpheus Island Research Station in Halifax Bay, north of Townsville. Along with the initial rollout of the receiving networks, more than 100 large reef fish (coral trout, red throat emperor, three species of sharks) were tagged on the southern reefs and 20 coastal fish (barramundi, mangrove jack) under the AIMS wharf. The Orpheus Island network is being used by at least one JCU student researcher. Starting in 2011-12, we will deploy a large number of receivers in the reef matrix offshore from Townsville that will complement a dense and extensive array maintained in Cleveland Bay by researchers in the JCU Fishing and Fisheries Centre. Both AIMS and JCU researchers will work closely in the next Quadrennium to tag a variety of reef and coastal species to learn more about the environmental and seasonal drivers of movement and habitat use. Some of these studies will form the basis of major projects in the NERP TE Hub with the common aim being to evaluate the effectiveness of current spatial closures on protecting fish stocks. In some species, of course, this will simply not be possible as evidenced by a validated record of a large bull shark that was tagged in Sydney Harbour then detected off Townsville before returning to New South Wales.

Planned Outputs

- Biodiversity changes on mid-shelf reefs eight and 10 years after rezoning (since 2004);
- Condition and trend data for the GBR over 28 and 30 year periods (since 1986);
- Baseline data from potential long-term monitoring sites in deep water (2 latitudes, 2 coasts);
- Baseline data from shallow water reef environments in Torres Strait;
- Data on the movements of reef and coastal fishes, including sharks, on both coasts; and
- Data on the efficacy of current marine protected area boundaries for mobile predators.

Desired Outcomes

- Increased certainty about the performance of current zoning for biodiversity conservation in Australia's most significant coral reef systems (GBR, Ningaloo Reef Tract);
- Sustainable futures for valuable fish stocks by adequate protection of egg production;
- Increased capability for self-management of marine resources by Torres Strait communities; and
- Increased awareness by all of changes in marine communities (below diver accessible depths).

Key Research-users

Marine industries (marine tourism, fishing, offshore oil and gas); Regional Authorities (GBRMPA, TSRA); Government Departments (DEEDI, DERM, DEC, DSEWPac); NGO (marine conservation); academic researchers including students (users of the public IMOS infrastructure).

Initial Focus of Plan

- Continue the GBR long-term reef health surveys started in 1986 (now biannually);
- Continue biannual surveys of 26 matched reef pairs on the GBR started in 2004;
- Continue regular monitoring of Scott Reef started in 1994;
- Continue to support one annual AUV mission by IMOS on east and west coasts;
- Collaborate with LSMU to design and implement a monitoring program for Torres Strait;
- Establish acoustic receiver array on mid- and outer-shelf reefs off Townsville;
- Establish acoustic outposts on oceanic reefs to track animal movements from Ningaloo Reef; and
- Tag and release sufficient animals to capture advantage from all AATAMS investments.

Performance Measures

- Uptake of AIMS data in the next GBR Outlook Report (2014);
- Self-managed reef monitoring by the TSRA by 2015;
- Co-investment by oil and gas industry in monitoring projects (e.g. Scott Reef);
- Maintenance of the AATAMS infrastructure (central and southern GBR, NRETA);
- Peer-reviewed publications from the long-term monitoring projects;
- Peer-reviewed publications on the performance of the GBR Zoning Plan (2003); and
- Peer-reviewed publications on movements and habitat use by mobile marine animals.

KEY RESULT AREA 3. PATTERNS AND PROCESSES IN TROPICAL MARINE BIOLOGY

Synopsis: Projects that add value to AIMS investments in long-term monitoring and/or large-scale assessments through conversion of the data to knowledge and action. The intention is to describe key ecological processes so that they can be included in predictive models or test hypotheses relevant to current theoretical problems in tropical ecology. We will also explore new methods for the assessment of biodiversity that increase efficiency, effectiveness, or drive down the cost of observation.

Activities under this Key Result Area will result in four streams of research:

Project 1. Ecological analysis and synthesis

In the last Quadrennium, the peer-reviewed scientific literature carried a strong debate about a significant decline in coral cover on the GBR between the 1950's and the start of the AIMS Long-term Monitoring Project (LTMP) in 1986. While the pre-industrial levels of coral cover may never be known with great certainty, the LTMP has shown an unequivocal reduction of more than 10% over the last 26 years. Between 1986 and 2005, crown-of-thorns starfish (COTS) were the major agent of change responsible for about 40% of coral loss. Since then, five severe tropical cyclones have raised the relative importance of physical breakage to the same level as the starfish predation. Looking into the future, no management response is possible to reduce the impact of future cyclones on the remaining coral cover. On the other hand, COTS control is more feasible and AIMS will sponsor an international workshop in 2012, timed with the International Coral Reef

Symposium in Cairns, to explore whether this option is a desirable strategy to build reef resilience to future change.

A significant project in the NERP Tropical Ecosystems Hub will relate biotic diversity of the GBR to spatial, environmental, and temporal drivers using a new statistical model of diversity developed by AIMS during the last Quadrennium. This project will combine diverse long-term and large-scale data sets from the GBR (coral cover and diversity, COTS abundance, seabed biodiversity, water quality data, bleaching patterns, cyclone impacts, and physical oceanography) to identify functional relationships that will be interpreted in the context of risk, zoning and management. Additional analysis will explore the ecosystem processes affecting reef resilience on the GBR, so that management options (such as direct action on COTS) can be developed and actions prioritised in terms of sustaining ecosystem function through periods of increased disturbance anticipated under future climate change scenarios.

AIMS will also partner with six other research providers in the NERP Marine Biodiversity Hub to work with the Marine Branch of DSEWPaC to strengthen evidence-based decision making in the Australian Marine Jurisdiction outside the GBR. The immediate goals will be information to support the Commonwealth marine bioregional plans, and the National Representative System of Marine Protected Areas (NRSMPA). For example, there is a need for nationally consistent monitoring, evaluation and reporting of biodiversity within these managed marine areas.

Project 2. Innovative tools for biodiversity assessments

Concern about the condition and trends of coral cover in the GBR rest on the assumption that coral cover is a major driver of other reef biodiversity. This is known to be true for the majority of small reef fishes and the myriad invertebrates that shelter in the complex topography of healthy reefs. Current monitoring is therefore based on tracking the status and trends in corals and fish because they are robust indicators of the values that visitors appreciate in a healthy reef. It is recognised, however, that more sensitive indicators of environmental pressure may be extracted from monitoring the tens of thousands of tiny species but the question is how to do this in a cost-effective manner?

In the last Quadrennium, the CReefs Australia Project undertaken as part of the global Census of Marine Life revealed just how much there is still to learn about the full expression of biodiversity on coral reefs. Without going down to the microscopic realm, the Project discovered over 1,000 new species in places with a long history of research. CReefs tested and validated a new way of sampling some of this cryptic biodiversity using metagenomic sampling applied to bulk samples collected using standardised crevice collectors (aka Autonomous Reef Monitoring Structures or ARMS). ARMS represent just one example of a potentially more cost-effective alternative to diver-based surveys to monitor reef health. Such methods can drive down the cost of observation and/or extend observations to places inaccessible to divers such as deeper environments.

Project 3. Demographic processes

The dynamics of marine populations are driven to a substantial extent by variations in the replenishment of populations with one of the more significant factors being the connectivity to other spawning sources. The Tropical Marine Biodiversity Team will continue some fundamental lines of enquiry into the replenishment of marine (especially fish) populations with tasks on larval dispersal, pre- and post-settlement processes. Most of these tasks will be supported by funds from the Australian Research Council and are likely to involve research training and early career researchers. One piece of fundamental knowledge that would find very strong uptake by users is quantifying the export of recruits from protected brood stocks in GBR Green Zones to exploited populations in GBR Blue Zones as that is a major justification for creating 'no-take' zones in the marine environment.

Project 4. Benthic ecology

Marine ecosystems in north Western Australia are different from their counterparts on the east coast in the diversity and abundance of marine sponges. In the last Quadrennium, limited sampling of the benthos seaward of the Ningaloo Reef Tract yielded more than 200 species of sponges, including new records, from collections made during a single voyage of discovery. As active filter feeders, capable of processing large volumes of water on a daily basis, we assume that sponge communities are feeding on high particulate loads in the water column and transferring substantial quantities of carbon from the water to benthic sinks. If so, the rate of benthic-pelagic exchange is important and needs to be quantified before we can have accurate models of food webs and nutrient fluxes for this region.

Planned Outputs

- Value-adding synthesis of AIMS long-term investments in marine monitoring and surveys;
- Workshop on crown-of-thorns starfish in 2012;
- Predictive model of GBR biodiversity based on the major environmental drivers;
- New understanding of the replenishment of fish populations;
- New data on the evolution of Australasian skates and rays;
- Contribute data to the international sharks and rays Tree of Life project;
- Understanding species diversification processes and biogeographic barriers (e.g. squat lobsters);
- New data on the diversity, ecology and physiology of WA sponges; and
- Trials of technology tools aimed at driving down the cost of monitoring.

Desired Outcomes

- A high proportion of AIMS historical data converted to knowledge used by marine managers;
- Cheaper and/or more cost-effective monitoring of marine systems;
- Reliable risk models for processes threatening marine biodiversity; and
- Predictive models of ecosystem performance facilitating management strategy evaluation.

Key Research-users

Marine tourism; DSEWPaC, GBRMPA, WA Department of Environment and Conservation.

Initial Focus of Plan

- Establish AIMS position on the outlook for coral cover on the GBR and test with stakeholders;

- Explore options for halting or reversing the decline of coral cover through management actions;
- Mine AIMS long-term data sets for drivers of change;
- Find opportunities for further development of ARMS into rapid assessment tools; and
- Conduct functional studies of the sponge communities off North West Cape, WA.

Performance Measures

- A consensus position on the outlook for coral cover on the GBR;
- New time-series analyses suitable for monitoring data;
- Squat lobsters added to the international DNA-barcode database;
- At least one new application of ARMS validating this new sampling method;
- Enhanced capability at AIMS for deepwater assessments;
- Uptake of AIMS data in the next GBR Outlook Report (2014); and
- Peer-reviewed publications.

KEY RESULT AREA 4. TROPICAL AQUACULTURE

Synopsis: Projects that focus on the domestication of wild stocks to support profitable aquaculture industries in tropical Australia with new knowledge and/or practices of animal husbandry, nutritional adequacy, microbial health, and systems design applicable to the mass propagation of larvae. Apply the same skills to captive coral populations with a quadrennium goal being to spawn corals out of season to provide coral larvae for experimental purposes throughout the year.

Activities under this Key Result Area will result in two streams of research:

Project 1. Domestication of tropical rock lobsters

The demand for seafood continues to increase nationally and internationally against a backdrop of limited supply⁸. Despite being a seafood producer with the third largest EEZ in the World, Australia presently imports about 70% of its seafood. While the domestic market remains so sensitive to the cost of production, Australian producers require niche markets for high value products such as tuna, pearls, abalone, or lobsters.

The tropical rock lobster, *Panulirus ornatus*, meets many criteria as a valuable product that could be supplied to an established market with high demand and strong growth potential driven by the rapid expansion of the middle-class in Asia. This animal is communal, tolerant of high densities, and has fast growth rates. It would be an ideal candidate for a niche market species except that its lengthy larval phase, as with many other marine species, is a severe bottleneck to mass production. Part of the difficulty arises from reproducing the natural conditions of its oceanic nurseries in the hatchery. In the last Quadrennium, progress at AIMS included the replacement of wild feeds with an artificial diet (producing optimal growth and lipid profiles comparable to wild-caught larvae) and dramatic improvements in survival to the final metamorphosis through good control of disease. It also included the first spawning from a second generation individual raised from an egg.

The final metamorphosis (from phyllosoma to puerulus) has proved to be the toughest hurdle yet with the current assumption being a nutritional deficiency or the absence of a metamorphic trigger. The team will continue to rear cohorts under different conditions in

⁸ <http://www.daff.gov.au/agriculture-food/food/national-food-plan;>
http://www.aspi.org.au/publications/publication_details.aspx?ContentID=204

an attempt to identify the missing element whilst broadening its skill base to include the propagation of other marine species.

Project 2. Coral Breeding

While AIMS scientists have experimented extensively with reef corals, past experiments have been of relatively short duration and always started with freshly collected material. When the National Sea Simulator (SeaSim) is operational, one part of the facility will be reserved for a captive coral bank that will be used to grow nubbins for future experimental work. A second goal is to maintain coral health to a level where they will spawn naturally in captivity and to entrain gametogenesis to different cycles by manipulating the light and temperature regimes in different aquaria. The 'proof of concept' will be to have more than one coral spawning event each year and the plan is to have year-round access to ripe corals.

The ready availability of gametes, zygotes and planulae produced in a laboratory setting would be a major resource for experimentalists, evolutionary biologists, and microbiologists. It would be especially beneficial to those, including the Marine Microbes and Symbioses Team, who seek to understand the coral-zooxanthellae symbiosis at a fundamental mechanistic level. This would potentially open the door to answers about the real ability of reef corals to adapt to warming and acidifying oceans.

Planned Outputs

- ▣ Continuous improvement in the development of formulated larval diets;
- ▣ Continuous improvement in microbial management technologies;
- ▣ Understanding of coral brood stock nutrition and health in captivity;
- ▣ Captive corals held for more than 12 months;
- ▣ Coral spawning in captivity; and
- ▣ Experiments to time-shift coral reproductive cycles.

Desired Outcomes

- ▣ A new and profitable aquaculture industry for northern Australia based on lobsters;
- ▣ A nutritionally complete larval diet for optimal growth and health of larval lobsters;
- ▣ Microbial control in larval hatcheries achieved entirely by natural methods; including probiotics;
- ▣ A sustainable supply of propagated corals for experiments;
- ▣ Coral brood stock with high nutritional and health status; and
- ▣ Coral spawning "on demand".

Key Research-users

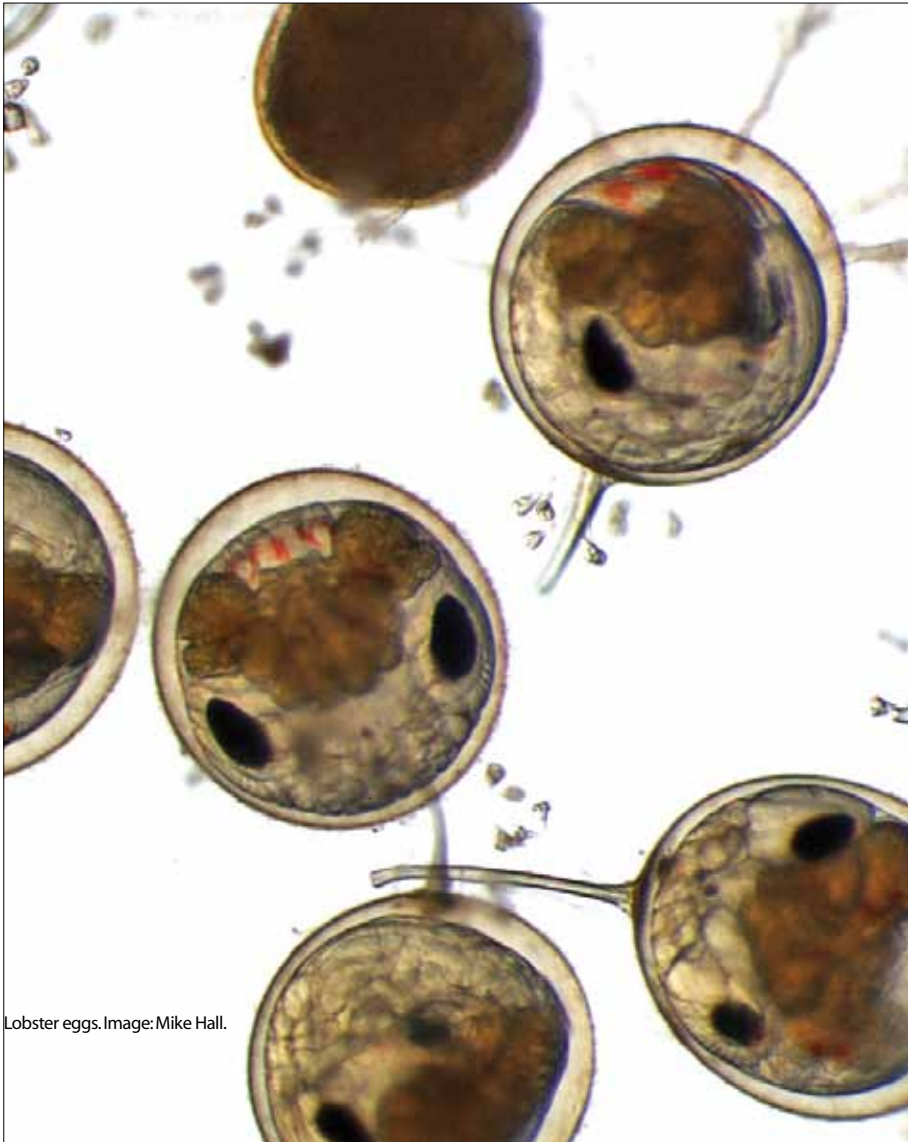
Aquaculture and aquarium industries; researchers (Coral Spawning Facility).

Initial Focus of Plan

- ▣ Raise multiple cohorts of larval lobsters to find the trigger for puerulus production;
- ▣ Continue development of probiotic treatments for improved larval health;
- ▣ Experiment with dietary triggers for metamorphosis to the puerulus stage;
- ▣ Establish pilot scale facilities for holding and propagating reef corals;
- ▣ Measure the long-term effects on condition and function in captive corals; and
- ▣ Optimise species selection and holding conditions for coral brood stock.

Performance Measures

- Number of cohorts resulting in juvenile lobsters;
- Survival of corals at one year after collection;
- Corals spawn in captivity;
- Viability and quality of spawn from captive corals equivalent to fresh stock;
- Coral spawning out of phase with wild populations; and
- Peer-reviewed publications.



Lobster eggs. Image: Mike Hall.

Permanent transects on inshore reefs that are surveyed every year to quantify changes of the condition of the coral communities. Close examination of the composition and condition is used for the assessment of impacts of land runoff and other disturbances on inshore reefs of the GBR. Image: AIMS Water Quality and Ecosystem Health Team.



Key Result Areas to be delivered through the *Water Quality and Ecosystem Health Team*

- 5) Human Impacts on Water Quality
- 6) Shelf-scale Pelagic Ecosystem Processes

INTRODUCTION

The health of coral reefs and other tropical marine ecosystems (e.g. seagrass) depends to a large extent on the quality of water in which they live. Sedimentation and turbidity regimes, the amount and type of organic matter inputs, presence of contaminants, nutrient availability, salinity, acidity, and temperature can all strongly influence the productivity, function and resilience of these ecosystems.

The primary causes of observed declines in coastal water quality and ecosystem health are increasing human populations, land use practices in the adjacent catchments, urban infrastructure and industrial development in the coastal zone.

The two research challenges for the AIMS Water Quality and Ecosystem Health Team (WQEH) are to understand the human and environmental drivers of water quality, and to forecast the responses of key components of ecosystems to changing water quality.

This research requires multidisciplinary knowledge (e.g. ecology, biogeochemistry, physiology, oceanography, and molecular genetics) integrated by spatial and process models. Research topics will range from fundamental benthic ecology and pelagic foodweb studies to applied studies for the monitoring and assessment of the impacts of coastal development.

The geographic focus of the Team's research will remain the GBR because the strong population growth and coastal land uses along the Queensland's northeast coast threaten biodiversity values and reef resilience in some inshore sections of the World Heritage Area⁹. By comparison, much of tropical Australia (NT, WA) remains lightly populated and we will use the more remote parts of these coasts as learning landscapes while collecting baseline data ahead of more intensive development there. We will also shift more effort to assessing the impact of urban and industrial development of the

⁹ GBR Outlook Report (2009)

coastal zone associated with significant growth in port infrastructure required to support the current boom in export commodities. Some of our research will be undertaken in neighbouring countries that are coping with extreme pressures on the marine environment beyond those likely ever to exist in Australia.

During the next four years, the Water Quality and Ecosystem Health team will conduct scientific research designed to fill critical knowledge gaps in two Key Result Areas.

KEY RESULT AREA 5. HUMAN IMPACTS ON WATER QUALITY

Synopsis: Projects that focus on the quality of coastal receiving waters and the cumulative threats posed by multiple anthropogenic pressures.

Activities under this Key Result Area will result in three streams of research:

Project 1. Water quality of the Great Barrier Reef

Land use practices that increase soil erosion in coastal catchments adjacent to the GBR have increased the loads of sediments four-fold in river runoff since 1850. As a result of increased erosion and the use of agriculture fertilizers, phosphorus levels have increased three-fold, and the export of nitrogen has at least doubled. Persistent pollutants from agrochemicals (e.g. herbicides) can be detected in the water and found buried in the coastal sediments. Following a scientific consensus statement in 2003 on the state of the problem, the Australian and Queensland Governments have committed \$375 million to a decadal Reef Plan¹⁰ designed to halt and reverse the decline in water quality entering the reef by 2013, and to ensure that by 2020 the quality of water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the GBR.

AIMS provided much of the long-term data considered when forming the scientific consensus statement reflecting our long history in measuring water quality in the coastal zone of north Queensland. As a partner in Reef Plan, we have led a major part of the marine monitoring component since 2005 and will be involved in numerous process studies as part of the NERP Tropical Ecosystems Hub. Examples of the contributions that we plan to make are the determination of the half-lives of organic contaminants in marine receiving waters, and multifactorial experiments to determine the relative and synergistic effects of sediments and nutrients under different regimes of light, temperature, salinity, and pH (see Project 2). Reliable estimates of these critical rate processes are needed to build the next generation of receiving waters models that will underlie the delivery of decision support tools to be used by coastal managers

In the last Quadrennium, AIMS and CSIRO collaborated to build a three-dimensional model of water circulation covering the whole of the east coast of Queensland and half of the Coral Sea with seed funding from the Reef Rescue Program delivered through the Marine and Tropical Sciences Research Facility (MTSRF). The Great Barrier Reef Foundation provided corporate donations to couple this model with catchment models developed by CSIRO (WaterCAST, SedNET) into an orchestration known as eReefs¹¹. In the new Quadrennium, eReefs will move beyond the pilot phase with a five-year \$25 million development plan to convert this modelling platform into a robust monitoring, reporting, and decision support tool for managing water quality in the GBR World Heritage Area.

¹⁰ <http://www.reefplan.qld.gov.au/index.aspx>

¹¹ <http://www.barrierreef.org/OurProjects/ZooXFund/CurrentResearchProjects.aspx>

Current partners in eReefs are AIMS, Bureau of Meteorology (BOM), CSIRO, Great Barrier Reef Foundation, and the Queensland Government.

Once eReefs is developed to an operational state, AIMS will deliver real-time data streams from the IMOS infrastructure scattered through the GBR that will be assimilated into the modelling to ensure its fidelity and realism allowing forecasts to be made about particular events (e.g. floods, cyclones) as they occur. Since this is the basis of modern weather forecasting, BOM brings invaluable experience to the development task and may become the eventual operator of the mature system.

Project 2. Multiple pressures on coastal ecosystems

Human activities on the land have increased the runoff of nutrients, sediments, and contaminants to rivers and hence to the oceans. Once in the receiving waters, excess sediments can lower light levels under turbid plumes and reduce the productivity of benthic primary producers. After delivery to the coastal zone, fine sediments can accumulate near the coast in shallow water for long periods and be resuspended by winds and waves, producing chronic turbidity. In calm periods, the sedimentation of fine mud particles can foul benthic surfaces and be lethal to small sessile life, especially for the vulnerable spat of many animals. The fouling can be more extreme in cases where excess nutrients cause sticky organic flocs produced by microbial decomposition to bind particles into aggregates that clog the feeding apparatus of filter feeders and prevent the recolonisation of hard surfaces by tiny animal life including propagules. The example of “muddy marine snow” illustrates the potential for two stressors (sediments, nutrients) to interact synergistically to produce a more lethal combination.

As a marine agency, AIMS additional contributions to eReefs will revolve around the data and process understanding required to extend and validate the marine receiving waters component into one capable of tracking and predicting the transport (and transformation) of river loads (freshwater, sediments, nutrients and contaminants) once discharged into the marine environment. Examples of contributions that we plan to make are the determination of the half-lives of organic contaminants in the marine receiving waters, and multifactorial experiments to determine the relative and synergistic effects of sediments and nutrients under different regimes of light, temperature, salinity, and pH. In the new Quadrennium, our ability to handle the required multifactorial designs will be enhanced by the National Sea Simulator. Several of these tasks will be supported by the NERP Tropical Ecosystems Hub and shaped by inputs from the Reef Plan partners. This process understanding will be integrated into eReefs through close collaboration with marine biogeochemists and modelling groups from CSIRO.

Project 3. Environmental impacts of coastal development

While much of our past work has concerned downstream impacts from farming, we have anticipated the need for better knowledge and tools to assess the potential impacts of urban and industrial development along the coast. A key focus will be on marine dredging activities. Dredging is nearly always involved in the development and maintenance of ports, harbours, and marinas. The recent boom in commodity exports from Queensland and WA is driving an unprecedented expansion of coastal shipping facilities and has led to the creation of a new Node in WAMSI for research into the impacts of dredging. Dr Ross Jones, from AIMS Perth laboratory, has been appointed as the inaugural Node Science

Leader. In anticipation of the required research, one section of the National Sea Simulator will be equipped with infrastructure capable of generating and maintaining realistic exposures to acute and chronic turbidity and sedimentation regimes.

In the Northern Territory, the decision of INPEX to pipe natural gas from WA to a shore-based LNG processing plant in Darwin Harbour will involve bringing the pipeline through NT waters and dredging of the harbour for port development and to allow the safe passage of larger vessels. In the last Quadrennium, AIMS supplied significant advice and research for a number of issues within the harbour and in 2010-11 arranged for a full bathymetric survey through its MOU with Geoscience Australia. In addition, AIMS maintains one of the IMOS National Reference Stations¹² outside the harbour limits. This complex mooring provides real-time data streams on the physical environment to provide context for quarterly biogeochemical sampling at the NRS site. Darwin Port Corporation has expressed interest in co-investing with IMOS in complementary infrastructure inside the harbour.

The extended boom in commodity exports anticipated from northern Australia is also leading to demand for services by the WQEH team in other expanding ports (notably Gladstone Harbour) as well as mining operations to the east of Darwin (Gove, Gulf of Carpentaria). These operations have various needs requiring skills in hydrodynamic modelling, environmental surveys, ecotoxicology, and risk assessment.

Planned Outputs

- Continued monitoring of GBR water quality and inshore reef health for Reef Plan;
- Process models for coastal turbidity downstream of Wet Tropics rivers;
- Improved algorithms for monitoring sediment loads and water clarity by remote sensing;
- Knowledge of herbicide persistence and the impacts of chronic low level exposures;
- Ecological risk assessments by NERP Tropical Ecosystems Hub for GBR water quality;
- Process understanding for the biogeochemical sub-model of eReefs;
- Process and risk models for dredge plumes;
- Water quality monitoring data and environmental health assessments for Darwin Harbour; and
- Environmental assessments from coastal sites in WA, NT, and Queensland.

Desired Outcomes

- A successful outcome from Reef Plan that reduces the impact of terrestrial runoff on the GBR;
- Greater use of evidence-based decision processes leads to improved coastal water quality;
- Reduced business risk and expense associated with gaining environmental approvals; and
- Results from the WAMSI Dredging Node influencing decisions by industry or regulators.

Key Research-users

Governments (Australian, State, local), regulators, Ports Corporations, marine industries, NGOs.

¹² <http://imos.org.au/anmnrrs.html>

Initial Focus of Plan

- Reef Plan monitoring program;
- eReefs model;
- Experiments in SeaSim to measure multifactorial effects and interactions of common stressors;
- Ecotoxicology studies;
- WAMSI Dredging Node; and
- EIS studies from coastal developments adjacent to enclosed and coastal waters.

Performance Measures

- Satisfaction with AIMS delivery to Reef Plan;
- Updated risk assessments completed for GBR based on cumulative hazards;
- Validated and robust biogeochemical model of marine receiving waters embedded in eReefs;
- Successful leadership of the WAMSI Dredging Node;
- Number of innovative experiments using the new SeaSim Facility;
- Decision support tools for environmental management of Darwin Harbour;
- Timely delivery of client reports on environmental impacts of coastal and marine developments; and
- Peer-reviewed publications on cumulative impacts of multiple stressors on coastal life.

KEY RESULT AREA 6. SHELF-SCALE PELAGIC ECOSYSTEM PROCESSES

Synopsis: Projects that deliver better understanding of physical, chemical and biological ecosystem processes required for the development of balanced nutrient budgets and ecosystem simulation models.

Activities under this Key Result Area will result in three streams of research:

Project 1. Great Barrier Reef – Coral Sea connections

Continental shelves are complex mixing zones between the land and the ocean. On narrow shelves, a significant fraction of the terrestrial materials washing into the sea may pass quickly across the shelf to the deep ocean. On the broad continental shelves which border tropical Australia, most of this terrestrial material is trapped and recycled. All shelf systems continually exchange water and nutrients with the adjoining ocean. Ultimately, the productivity of benthic and pelagic ecosystems on tropical continental shelves depends on the magnitude and rate of biological cycling of nutrients from both land and ocean.

Shelf waters of the GBR mix continuously with adjoining oligotrophic (low nutrient) surface waters of the Coral Sea. Under the influence of currents, winds and tides, large volumes move back and forth across the shelf break. Our understanding of the volume and extent of this mixing, and its consequences, is not well constrained in current oceanographic models. Likewise, it has long been known that cool waters from the Coral Sea thermocline episodically upwell along the bottom on to the outer shelf of the GBR. These intrusions deliver additional nutrients from the thermocline to shelf ecosystems with significant effect on the biomass, distribution and productivity of outer-shelf benthic and pelagic communities. The broad-scale extent, frequency and magnitude of this upwelling are poorly understood although the IMOS infrastructure (oceanographic moorings, ocean gliders) now deployed along the shelf break represents the start of more intensive long-term monitoring of this open ocean boundary.

Estuarine and marine organisms, water, sediments and associated particulate and dissolved materials continuously move between the coastal zone shelf and the broader continental shelf. In the tropics, the coastal-shelf boundary is thought to be a major hot spot of rapid recycling of carbon, nutrients and other elements, characterised by potentially large fluxes of materials to the atmosphere. Over 25 years, AIMS has developed first-order budgets for elements such as carbon, nitrogen and phosphorus that have identified areas of the Great Barrier Reef coastal zone as major sinks for carbon and nitrogen derived from land. However, the flux of carbon between sea and atmosphere is unknown although coastal systems elsewhere have been shown to be major sources of carbon and other greenhouse gases to the atmosphere. To better understand the capacity of tropical coastal ecosystems to sequester carbon, these processes will be quantified in the context of a complete carbon cycle budget.

As a component of eReefs, this project will focus on developing a better quantitative understanding of the latitudinal extent, magnitude and frequency of shelf-break upwelling activity, and more precisely defining the cross-shelf gradients of nutrients, carbon and plankton stocks that are essential for modelling exchanges of materials between the GBR and the Coral Sea. This information will be essential to both develop and validate the eReefs models. This project will support annual voyages to sample physical, chemical, and biological oceanographic processes at several latitudes to calibrate and validate the model performance.

Project 2. Bio-physical oceanography of the North West Shelf and the Timor Sea

The North West Shelf and Timor Sea is Australia's contact zone with Asia and the most dynamic frontier of national economical development. Because of its remoteness, considerably less is known about the North West marine domain than other parts of the Australian marine estate.

Over four decades, AIMS has built considerable understanding of the bio-physical oceanography of the coastal seas of tropical Northern Australia. This work underpins both our capacity to understand water quality, productivity and food web dynamics in tropical marine ecosystems and to provide sound advice to users and managers of these systems. While a significant fraction of the team's activities will be focused on the GBR, research on the North West Shelf will provide important additional information on these high energy systems.

Shelf-scale process research in northwestern Australia will ultimately be integrated into the development of physical and biological simulation models. To be fully capable, these models must incorporate and assimilate the dynamic connections across both coastal and oceanic boundaries. In the new Quadrennium, AIMS will take a leading role in supplying the data sets needed to underpin and validate the biogeochemical model being developed for this region. The IMOS infrastructure deployed and serviced by AIMS (cross-shelf lines of oceanographic moorings in the Joseph Bonaparte Gulf, Kimberley, and Pilbara regions) will provide crucial data on currents, tides, and mixing processes to constrain a hydrodynamic model for the North West marine domain.

In the new Quadrennium, we will continue to collect data on physical and biological oceanography from the Kimberley coast of WA. This will be a significant contribution to the Kimberley Marine Research Program being developed by WAMSI to support the recent declaration of State and Commonwealth marine parks around this wilderness area.

Planned Outputs

- Validate estimates of cross-shelf mixing and nutrient fluxes in the GBR and North West Shelf;
- Measure shelf-edge exchanges of water and nutrient fluxes (upwelling) at the GBR shelf break;
- Complete the carbon cycle for the Hinchinbrook Channel;
- Baseline data for first order models of biological oceanography off the Kimberley Coast; and
- Descriptions of the key pelagic communities of the North West Shelf and their contribution to ecosystem structure and productivity.

Desired Outcomes

- New knowledge of carbon cycling in the tropical coastal zone transferred to global models to improve carbon accounting (net sink or source) and value essential ecosystem services;
- A robust shelf-scale biogeochemical model embedded in eReefs;
- Balanced shelf-scale nutrient budgets for the GBR and North West Shelf; and
- A model of nutrient cycling on a tropical macro-tidal shelf to inform coastal planning in Western Australia.

Key Research-users

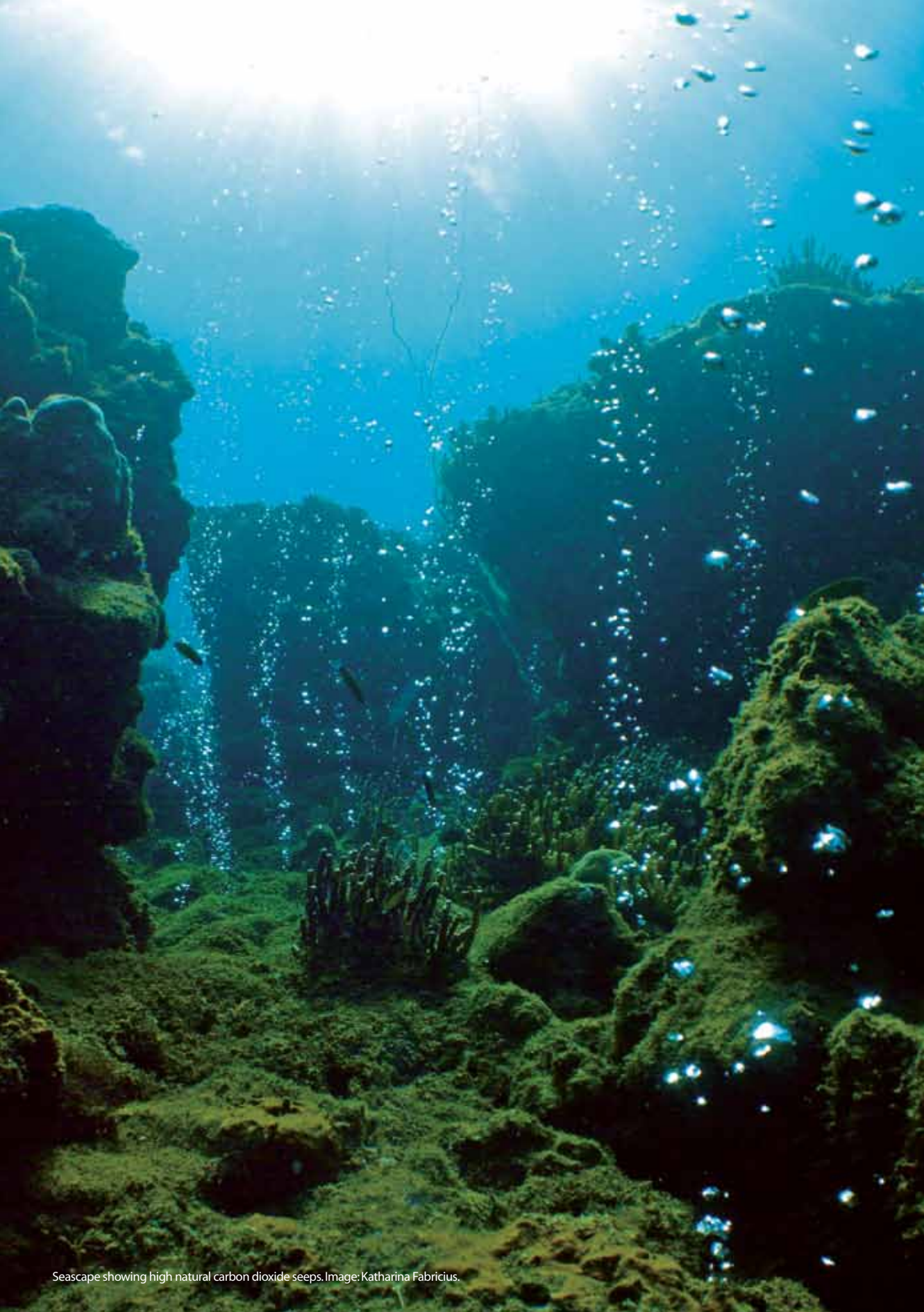
Governments, regulators, natural resource managers, marine industries, NGOs.

Initial Focus of Plan

- Identify regions predicted by shelf-scale hydrodynamic model to have persistent upwelling;
- Deploy oceanographic moorings to collect time-series on upwelling dynamics;
- Biological oceanography voyages inside and outside upwelling events to track fluxes;
- Deploy CO₂ sensors in the Hinchinbrook Channel; and
- Repeat oceanographic voyages off the Kimberley coast (in wet & dry Seasons).

Performance Measures

- Validated and robust biogeochemical model of marine receiving waters embedded in eReefs; and
- Peer-reviewed publications on coastal biogeochemistry and shelf-scale biological oceanography from tropical Australia (GBR, Kimberleys) and neighbouring countries.



Seascape showing high natural carbon dioxide seeps. Image: Katharina Fabricius.

Key Result Areas to be delivered through the *Climate Change and Ocean Acidification* Team

- 7) Australia's Tropical Seas – Past, Present and Future**
- 8) Resilience and Vulnerability of Coral Reefs in a High-CO₂ World**

INTRODUCTION

Australia's tropical marine ecosystems have entered an era of unprecedented climate and ocean change. The increase in atmospheric concentrations of greenhouse gases, especially carbon dioxide (CO₂), from the burning of fossil fuels is warming and acidifying the ocean surface waters faster than at any time in human history. Global climate change has led to a 0.5°C rise in tropical sea temperature over the last 100 years and recent years have been the warmest on record. Even if nations adopt mitigation strategies that keep CO₂ concentrations below 450 ppm (considered by many to be a tipping point), tropical marine climates will continue to experience rapid and significant changes predicted to cause organism and ecosystem decline.

There are numerous consequences of a high carbon emission path for tropical marine ecosystems. Firstly, ocean warming coupled with interannual variations of circulation at ocean basin scale increases the likelihood of thermal anomalies of more than one degree Celsius, which are the conditions for mass coral bleaching and mortality events. Secondly, while global climate models are yet to reach consensus on whether tropical cyclones will be more frequent, warmer oceans are likely to elevate their intensity. The passage of five severe Category 4-5 cyclones (Ingrid, Ului, Larry, Hamish, Yasi) in recent years almost doubled the contribution of cyclone damage to coral cover on the GBR since 1986 (AIMS LTMP records). Thirdly, around 25% of CO₂ emissions are dissolved into the ocean, gradually lowering its pH and compromising the ability of calcifying marine organisms to build and maintain calcareous structures. This is particularly threatening for coral reef ecosystems that are built through calcification. Finally, the Queensland climate has become more extreme over the last 100 years with stronger droughts alternating with very wet seasons (such as the extreme summer of 2010-11), which has proved especially damaging to people, property and prosperity.

Understanding how climate and ocean change threatens the health and functioning of tropical marine systems requires an integrated multidisciplinary research approach working at scales from organism to ecosystem, and learning from the past and present to make predictions for the future. Policy and management responses for adaption and mitigation require reliable and accurate understanding of the current and future risks to ecosystem goods and services, best delivered through working partnerships between scientists and managers. The research plan for the Climate Change and Ocean Acidification team is structured so that the problem of climate and ocean change is first understood in a historical context and then tackled in a resilience and vulnerability framework to predict how tropical biota and ecosystems will respond to climate and ocean change, with the intent of informing management and policy.

During the next four years, the Climate Change and Ocean Acidification team will conduct scientific research designed to fill critical knowledge gaps in two Key Result Areas.

KEY RESULT AREA 7. AUSTRALIA'S TROPICAL SEAS – PAST, PRESENT AND FUTURE

Synopsis: Projects that deliver historical information on past environmental conditions and coral calcification responses interpreted from proxy records deposited in the skeletons of massive corals.

Activities under this Key Result Area will result in two streams of research:

Project 1. Coral Sea and Great Barrier Reef

Climate change is not only a future phenomenon for Australia's tropical seas. Observational data since the 20th century already provide evidence of significant, though spatially variable, warming and recent acceleration in the rate of change. This trend is expected to continue for the foreseeable future due to greenhouse warming of the planet, with increased risk of coral bleaching caused by anomalous temperatures and theoretical risks to the calcification process caused by ocean acidification.

We know that the future will be different from the past but there is much debate about whether recent rates of warming are unprecedented at less than geological scales and whether corals have the ability to survive if ocean warming continues at the present rate. Observational records of coral reefs and instrumental records of tropical climates are just too short to provide the necessary perspectives on 1) the nature and causes of past inter-annual, decadal and longer-term climate variability, and 2) the responses of coral growth and ecosystems to a changing physical environment. Annually-banded massive coral skeletons, however, contain a permanent record of past growth rates, which vary with sea temperatures. Skeletal chemistry also contains other environmental signals that can be extended back hundreds of years from the present and the ability to date fossil corals to within a few years using the latest isotopic techniques can open time windows spanning hundreds of years from many thousands of years in the past.

AIMS holds a unique collection of long coral cores sampled from the length and breadth of the GBR (held in the Australian Core Coral Archive). These cores contain proxy records for past temperature, rainfall, soil erosion, and upwelling. In the 2011-15 Quadrennium, the archive will be sampled more comprehensively to provide a synoptic view of past changes in different regions of the GBR. Corals from the inshore GBR will be interrogated

for evidence of past flooding, which can be related to long-term weather variability driven by interannual variability such as El Nino-Southern Oscillation (ENSO) events and multi-decadal drivers like the Inter-decadal Pacific Oscillation. Corals from the outer shelf will be examined for what they can tell us about spatial and temporal signals in ocean upwelling.

Project 2. Indian Ocean

In the 2007-11 Quadrennium, a complementary archive of long coral cores was collected from sites in WA ranging from the Sahul Shelf (Ashmore Reef) to the Abrolhos Islands off Geraldton, which is currently the southern limit of massive corals on the west coast. Most of the corals came from oceanic locations or from sites adjacent to the arid coast. Consequently, they may not be as informative as corals of the GBR with respect to rainfall and cyclones (flood plumes) except in select locations. Nonetheless, the cores will contain reliable information on past temperatures and should capture the signal of ENSO variation on the west coast due to the exchange of water from the Pacific to the Indian Ocean via the Indonesian Throughflow. Corals from the Sahul Shelf should be ideal locations to record this activity and historical temperature will be cross-correlated with the ENSO signals revealed by rainfall variations on the east coast. This cross-correlation will reveal the extent to which global climate signals are linked or independent between ocean basins. Although the strength of the poleward Leeuwin Current down the west coast is known to fluctuate with ENSO activity in the Pacific Ocean, the Indian Ocean also has other drivers notably the Indian Ocean Dipole (IOD). Like ENSO, the IOD represents coherent and out-of-phase temperature anomalies across the ocean basin and is an important driver of terrestrial climate in parts of Australia. Information on these multi-decadal oceanographic drivers of climate could prove immensely valuable to global climate models if the signals are coherent and capable of validation against the much shorter instrumental record.

Planned Outputs

- Coral growth histories for Australia's tropical seas;
- Paleoclimate records of flood plumes and upwelling from the GBR; and
- Paleoclimate records of ocean variability from the Indian Ocean.

Desired Outcomes

- Coral proxy records produce reliable climatologies for northern Australia extending instrumental records from the recent past by three-fold; and
- Accuracy of regional climate forecasts improved by incorporating multi-decadal ocean variability into global models of coupled-atmosphere dynamics.

Key Research-users

Department of Climate Change and Energy Efficiency, GBRMPA, DERM, climate modellers including international programs such as PAGES¹³.

Initial Focus of Plan

- Determine spatial patterns of stable isotopes (Oxygen-18, Carbon-13) for GBR corals;
- Find geochemical proxies in coral skeletons for inshore water quality and oceanic upwelling; and
- Analyse growth variations from all coral cores collected from WA in the 2007-11 Quadrennium.

¹³ <http://www.pages.unibe.ch/>

Performance Measures

- Analyse at least 500 years of annual coral growth per year of the Quadrennium;
- Publish a climate history of tropical Australia on the AIMS web site; and
- Peer-reviewed scientific publications on coral growth and geochemistry.

KEY RESULT AREA 8. RESILIENCE AND VULNERABILITY OF CORAL REEF SYSTEMS IN A HIGH-CO₂ WORLD

Synopsis: Projects that deliver underpinning science to estimate the exposure, risk, and potential adaptation of corals, tropical fishes and coral reef ecosystems to climate change.

Activities under this Key Result Area will result in two streams of research:

Project 1. Ocean acidification and warming

Australia's coral reefs are some of the largest and richest tropical marine ecosystems on Earth. Many processes that make these ecosystems resilient to natural disturbances (such as cyclones) will potentially be compromised by climate change. This project will develop a mechanistic model for ecosystem resilience and vulnerability, suitable for testing with real data, in order to understand the key drivers of change in coral reef systems and to forecast future states under different climate scenarios.

Tasks within this project will deliver insights from observational, experimental, and/or modelling studies to tackle topical questions about how climate change in the ocean will affect ecosystem processes and function. Observational studies will include the 'state-of-the-art' wireless sensor networks (WSN) now operating on four different coral reefs in the GBR as part of IMOS. These WSN are transmitting real-time data on physical oceanographic variables from coral reefs in the southern, central and northern GBR. While offering regional context and early-warning of a build-up of heat stress, these networks are designed to gather information from multiple simultaneous deployments of sensors to link physics and biology at local scales. Intensive observations at this scale will be critical to inform and validate hypotheses about cause and effect from multiple stressors.

Experimental work on ocean acidification will be undertaken in natural arenas as well as controlled laboratory settings. In the new Quadrennium, we will take advantage of natural CO₂ vents (cold gas seeps) in Papua New Guinea (PNG) to provide a window into possible future states for coral reefs in a high CO₂ world. To the extent possible, we will use these natural gradients of ocean acidity to understand the impact of pH on critical processes like metabolism, calcification and coral growth in order to understand the scope for physiological acclimatisation and evolutionary adaptation and to predict ecosystem-level responses to global climate change. We will also work at other cold gas seeps to test the generality of our findings and build confidence around the future states for coral reefs glimpsed in PNG.

From 2013, AIMS will use the National Sea Simulator for multifactorial experiments that will inform predictive models about biological responses to change in the marine environment. In addition, SeaSim will be used to induce corals to spawn out of season, which would greatly enhance opportunities for experiments on the most vulnerable life stages of corals, as well as providing facilities to support multi-generational investigations of the capacity of tropical fishes to adapt to future climates.

Project 2. Risk maps and adaptive responses

While tasks under Project 1 will focus on the collection of data for process understanding, tasks in this project will focus on data synthesis and the development of spatially-explicit models around key themes of resilience and vulnerability, which are cornerstone concepts in reef conservation and management. Models incorporating process understanding from ecology, physiology and molecular/genetic sciences will provide a strong framework for decision support tools for marine parks managers. The overall objective will be to provide new quantitative insight into the impacts of high CO₂ on the ecological goods and services provided by Australia's coral reefs and to offer solutions to managers designed to defend and preserve the attributes of healthy ecosystems.

Planned Outputs

- Process understanding of the impacts of ocean acidification on marine organisms and ecosystems;
- Molecular markers found for thermal stress and adaptation in fishes and reef-building corals;
- Identification of key physiological and ecological processes in tropical fishes that confer intra- and inter-specific resilience to future ocean states; and
- Risk maps for the GBR under climate change scenarios.

Desired Outcomes

- AIMS data and models reduce uncertainty in environmental decision making by incorporating multiple factors and their interactions into a common framework accounting for cumulative effects;
- Models allow management strategy evaluation and identify strategies most likely to maintain maximum resilience in reef ecosystems; and
- AIMS data and models incorporated in decision support tools for reef policy and management.

Key Research-users

AMPTO, DCCCE, DSEWPac, DEEDI, DERM, GBRMPA, NOAA (Coral Reef Watch), Conservation NGOs.

Initial Focus of Plan

- Conduct multifactorial experiments to reveal the interactions between warming, dissolved nutrients, and acidification on demographic rates of key reef organisms to define "water quality";
- Collect information from natural cold gas seeps in proximity to modern coral reefs for essential calibration and validation of predictive models of biological and ecological responses to ocean acidification;

- Collect data on the physiological and reproductive performance of tropical fishes in current and potential future environments to predict impacts on species and food webs;
- Continue to search coral genomes for genotypes more tolerant of temperature variations in order to select breeding stock for hybridisation experiments using SeaSim; and
- Develop vulnerability and resilience models for reef systems affected by realistic future scenarios in water quality validated by other stakeholders.

Performance Measures

- Uptake of data and vulnerability maps into GBR Outlook Report (2014);
- Use of decision support tools by natural resource managers; and
- Peer-reviewed scientific publications.



Extracting coral cores in Western Australia. Image: Eric Matson.

Key Result Areas to be delivered through the *Marine Microbes and Symbioses* Team

9) Reef Symbioses in a Changing Ocean 10) Harmful Organisms

INTRODUCTION

Marine microbes encompass a wide range of the microscopic life forms found in the sea including viruses, bacteria, and micro-algae; groups that differ considerably in their biology. Although unseen, microbes constitute the vast bulk of marine biomass. They are the oldest life forms, the catalysts of energy transformation, and are fundamental to the major biogeochemical cycles that make Earth habitable for humans. They were the only kinds of life on the planet for approximately 80% of Earth's existence and all multicellular life depends on microbial processes.

The global oceans have been estimated to contain 1.3×10^{28} archaeal (single) cells, 3.6×10^{29} bacterial cells, and 4×10^{30} viruses. Current estimates of marine bacterial diversity range into the millions of distinct taxa. Recent applications of shotgun sequencing techniques that recover unique DNA sequences from bulk water samples and the use of 454 DNA tag sequencing indicate that marine microbial diversity may be some 10 to 100 times greater than predicted, and the vast majority are unknown organisms that exist as part of a 'rare biosphere'. Less than one percent of the microbes present in seawater can be cultured using conventional approaches, which is indicative of the state of our knowledge of this unseen world. Despite that, we know that microbial communities are the most significant decomposers and recyclers of nutrients in the oceans: hence an essential element in global cycles and among the most serious of information gaps when we try to forecast how ecosystems will respond to change.

Marine science cannot continue to overlook the unseen world of microbes and Australia must build capacity in this area because microbes will be among the first responders to climate change due to their short life cycles and rapid turnover. In a rapidly changing climate, they are likely to present future challenges to our society through adverse impacts on aquatic and human health.

Consequently, this is an urgent direction for the Institute. Over the new Quadrennium, we will consolidate and build our capacity by

focusing on two areas where microbial processes are clearly central to issues of immediate concern for all coral reefs: the nature of dysfunction in important symbioses of sponges and reef-building corals, and the causes and consequences of disease in corals and other invertebrates.

KEY RESULT AREA 9. REEF SYMBIOSES IN A CHANGING OCEAN

Synopsis: Projects into the mechanisms underlying the breakdown of important functional symbioses in tropical organisms (corals and sponges) and the chemistry of molecular signalling among symbiotic organisms.

Activities under this Key Result Area will result in two streams of research:

Project 1. Structure and function of microbial associations

'Coral symbiosis' is a mutually beneficial association between organisms of different species and is fundamental to the performance of reef-building corals and hence the existence of coral reefs. The combination of the coral animal host and its intracellular zooxanthellae, which are single cells capable of photosynthesis, captures more energy for growth by the coral than is available to the animal when relying on heterotrophic nutrition alone. The coral-algal symbiosis is a delicate partnership, however, that is disrupted by the combination of high temperature and strong light, which explains why coral bleaching is most often seen during summer. However corals can also bleach when sea temperatures are too cold, seawater salinity drops, or dissolved nutrient levels are elevated.

Until recently, coral bleaching looked like a simple mismatch between the needs of two mutualists but the coral 'holobiont' is now understood to include the coral, multiple genetic variants of zooxanthellae, fungi, endolithic algae, and many different bacteria. The interactions within this complex community will be the subject of research to understand the biochemical and molecular mechanisms involved in coral bleaching in order to improve our fundamental understanding of the coral-algal symbiosis and to help us to predict the stability and adaptability of this symbiosis to future conditions.

Marine microbes are involved in a variety of important symbiotic relationships with other invertebrates including sponges, tunicates, molluscs, sea urchins, and jellyfishes. Benefits for the animal host from these mutualisms include enhanced nutrition (as with the corals), waste recycling, and/or the production of secondary metabolites used in defence and immuno-competence. We will use sponges as another model system because these primitive animal hosts have an evolutionary history of 600 million years and therefore had the most time to develop sophisticated inter-kingdom relationships based on co-evolved biochemistry.

Project 2. Chemical communication from microbes

This project will have a number of elements. Firstly, it will investigate the important role of microbes in recycling essential nutrients in key coral reef invertebrates including corals and sponges. Specifically, it will focus on carbon, nitrogen and sulfur as essential nutrients being shuffled through symbiotic partnerships among reef invertebrates and the contribution of these exchanges to the genetic fitness of the partners. Symbiotic functions will be determined through the combined application of genetic, chemical and advanced imaging technologies to provide key insights into invertebrate symbioses and their vital

role in coral reef ecosystems. A second focus will be on inter-kingdom chemical signalling and communication in corals at the crucial stage of colonisation, metamorphosis, and establishment of the intracellular symbiosis. Finally, we will start an entirely new line of inquiry into the role of viruses in the coral holobiont. Gene exchange (among host species as well as between host and viral symbionts) will be investigated as this can lead to novel function as well as increased genetic diversity and therefore increase the scope for the holobiont to adapt to stresses including those from climate change.

Planned Outputs

- Tests of the stability of coral and sponge symbioses to environmental changes;
- Biochemical pathways specified for metabolic exchanges between hosts and symbionts;
- Chemical signals on natural surfaces identified that induce metamorphosis and settlement of coral and/or sponge larvae, and modes of action determined;
- Identify molecules used during quorum sensing by bacteria to promote or inhibit cell division; and
- Baseline information on the role of viruses in the coral holobiont.

Desired Outcomes

- Ability to predict the functional responses of corals and sponges to environmental stress;
- Inclusion of signalling molecules in spat collectors to promote coral restoration and rehabilitation; and
- Lineages of hybridised corals that are more tolerant of temperature variations.

Key Stakeholders

Academic science community, GBRMPA, DERM, AMPTO.

Initial Focus of Plan

- Identify and visualise the functional role of coral and sponge associated bacteria and viruses;
- Test the stability of candidate symbioses to environmental stresses (e.g. water quality, temperature and pH) in controlled, multifactorial experiments using the SeaSim Facility;
- Isolate, identify and maintain axenic zooxanthellae cultures from different genetic background to explore the biology of these ubiquitous dinoflagellate symbionts of many reef animals; and
- Identify chemical cues involved in coral settlement and metamorphosis and determine their specificity, distribution and effect on gene expression in coral larvae.

Performance Measures

- Supply axenic zooxanthellae cultures to research partners to assist their research;
- Techniques available to facilitate coral settlement and metamorphosis; and
- Peer-reviewed scientific publications.

KEY RESULT AREA 10. HARMFUL ORGANISMS

Synopsis: Projects that seek improved understanding, robust detection methods, and predictive risk analysis of marine microbes threatening environmental and human health.

Activities under this Key Result Area will result in two streams of research:

Project 1. Pathogens causing coral diseases

Not all associations between multicellular organisms and microbes are symbiotic and beneficial. Many are pathogenic and reef-building corals are vulnerable to multiple diseases. While disease has so far caused minor coral mortality on the GBR, there is no guarantee that this will remain so. Microbial diseases have contributed significantly to the greatly diminished reef systems of the Caribbean by causing the widespread death of corals, urchins, sponges and sea fans.

LTMP surveys have shown major outbreaks of the coral disease, White Syndrome, after anomalously hot years caused mass coral bleaching but only on reefs with high coral cover. While this suggests that environmental stress is associated with disease, the trigger for a disease outbreak obviously is more complex than temperature history alone and therefore currently beyond forecast. Furthermore, White Syndrome is just one among many coral diseases.

The project will develop detailed models of microbial disease in the coral reef ecosystem with a focus on the interaction between water quality (potential stress from high nutrient loads and abnormal pH) and water temperature on the microbial communities associated with corals. The study will start with observations on the bacterial assemblages found in the mucus of unstressed corals to understand what is normal. The response of the holobiont (coral host, algal symbionts, and microbial associates) to external stresses will be tested through multifactorial experiments, designed to identify vulnerability thresholds, using the National Sea Simulator. The key objective of this project is to increase our ability to forecast changes in pathogen virulence as a natural but unwanted response to environmental change.

Project 2. Biotoxins

Biotoxins are re-emerging as an issue in the marine environment and encompass many different examples from food-poisoning, through contaminated fish and shellfish, to venomous animals, and even toxins causing diseases of key reef organisms. Box jellyfish represent some of the most venomous animals in our marine environment, yet very little is understood about their ecology and/or toxicology. This project will provide a fundamental understanding of the structure, function and mode of action of poorly known toxin families produced by the box jellyfish, which should assist in the development of new and/or improved treatments for humans affected by marine stingers. At the same time, the jellyfish provides a valuable model organism to develop the techniques and approaches critical to modern investigations of microbial biotoxins.

Another task will prepare for the growing need to detect biotoxins in food chains (seafood security) and coastal receiving waters in order to understand their risks to environmental and human health. The immediate focus of the task will be improvement of current detection methods and the development of ecogenomic tools and diagnostic kits. The long-term plan will be marine microbial observing systems capable of detecting

perturbations in the environment before they become a problem for other organisms, including humans.

Planned Outputs

- Enhanced understanding of key diseases and disease mechanisms in corals including the drivers of pathogen virulence and host resistance;
- Enhanced understanding of the evolution of marine toxins and biotoxins, their function in the marine environment, and the organisms such as cyanobacteria and jellyfish that produce them; and
- Better (more selective, more sensitive) methods of detecting toxic organisms and/or their toxins in the marine environment and/or marine organisms.

Desired Outcomes

- Improved ability of natural resource managers to forecast the incidence and/or virulence of outbreaks of coral disease leading to proactive management and/or mitigation responses;
- Improved seafood security;
- Improved aquatic environmental health;
- Improved human health with respect to water-borne diseases or marine biotoxins; and
- More effective, species-specific treatments for box jellyfish stings in humans.

Key Research-users

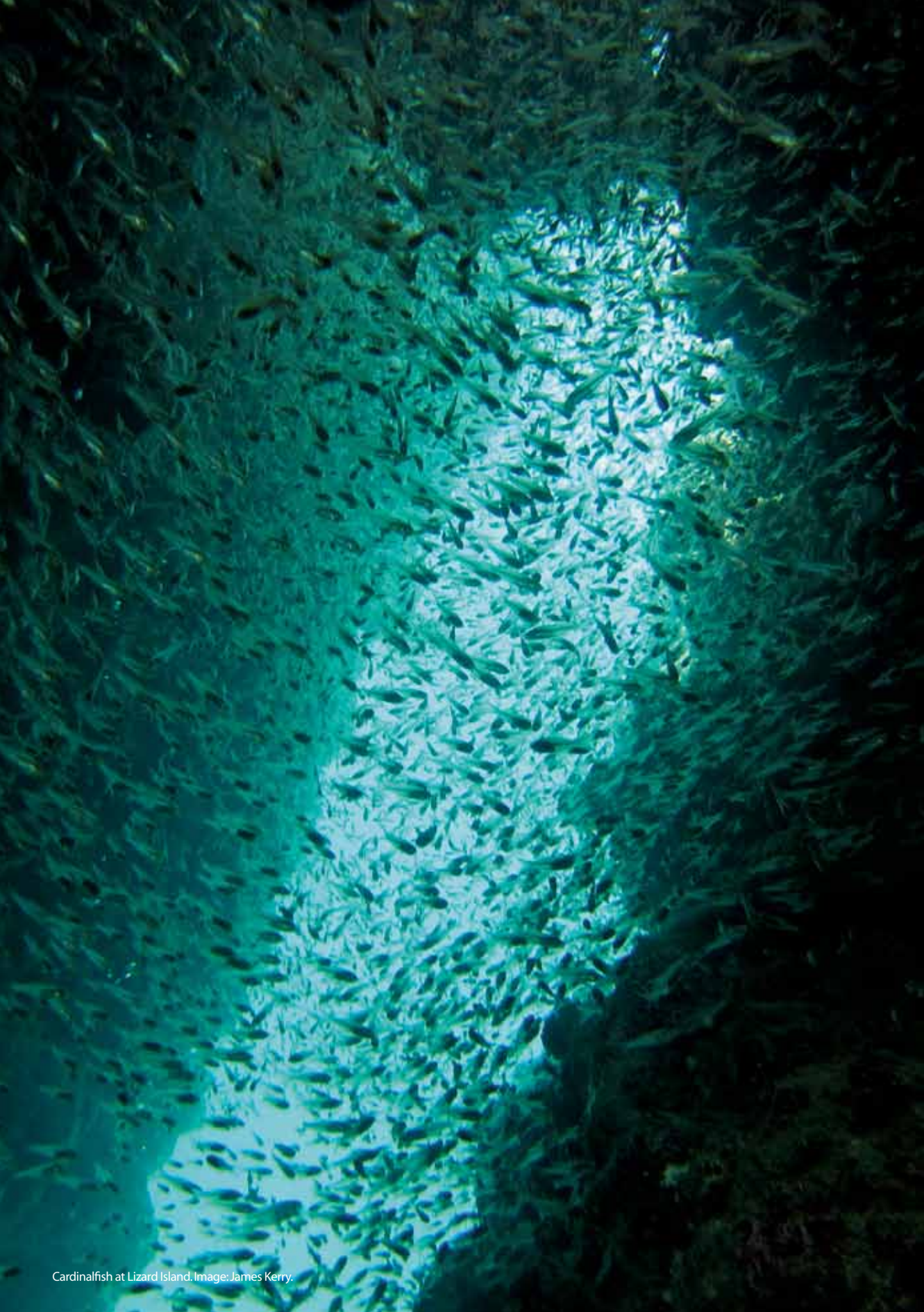
GBRMPA, AMPTO, commercial and recreation fishers, seafood producers and consumers, aquaculture industry, local Councils (beach safety).

Initial Focus of Plan

- Isolate and identify the toxins in the venoms of Australia's most harmful box jellyfishes *Chironex fleckeri* and *Carukia barnesi*;
- Establish field sites at one or more of the GBR island research stations to support collaborative field studies into coral disease with emphasis on the factors promoting disease virulence and host vulnerability; and
- Establish model host experimental systems to elucidate the fundamental processes (host, causative agents, environmental drivers) that result in diseases in tropical marine invertebrates.

Performance Measures

- Provide a scientific foundation for more effective box jellyfish antivenoms;
- Coral disease included in risk and vulnerability assessments for the GBR Outlook Report (2014);
- Rapid diagnostic test for *Vibrio coralliilyticus* in water, sediments, and tissues; and
- Peer-reviewed scientific publications.



Cardinalfish at Lizard Island. Image: James Kerry.

Appendix 1. National Research Priorities and Goals

A. An Environmentally Sustainable Australia

Transforming the way we utilise our land, water, mineral and energy resources through a better understanding of human and environmental systems and the use of new technologies.

1. Water – a critical resource
Sustainable ways of improving water productivity, using less water in agriculture and other industries, providing increased protection of rivers and groundwater and the re-use of urban and industrial waste waters.
2. Transforming existing industries
New technologies for resource-based industries to deliver substantial increases in national wealth while minimising environmental impacts on land and sea.
3. Overcoming soil loss, salinity and acidity
Identifying causes of and solutions to land degradation using a multidisciplinary approach to restore land surfaces.
4. Reducing and capturing emissions in transport and energy generation
Alternative transport technologies and clean combustion and efficient new power generation systems and capture and sequestration of carbon dioxide.
5. Sustainable use of Australia's biodiversity
Managing and protecting Australia's terrestrial and marine biodiversity both for its own value and to develop long-term use of ecosystem goods and services ranging from fisheries to ecotourism.
6. Developing deep earth resources
Smart high-technology exploration methodologies, including imaging and mapping the deep earth and ocean floors, and novel efficient ways of commodity extraction and processing (examples include minerals, oil and gas) while minimising negative ecological and social impacts.
7. Responding to climate change and variability
Increasing our understanding of the impact of climate change and variability at the regional level across Australia and addressing the consequences of these factors on the environment and on communities.

B. Promoting and Maintaining Good Health

Promoting good health and well being for all Australians

1. A healthy start to life
Counteracting the impact of genetic, social and environmental factors which predispose infants and children to ill health and reduce their well being and life potential.
2. Ageing well, ageing productively
Developing better social, medical and population health strategies to improve the mental and physical capacities of ageing people.
3. Preventive healthcare
New ethical, evidence-based strategies to promote health and prevent disease through the adoption of healthier lifestyles and diet, and the development of health-promoting products.
4. Strengthening Australia's social and economic fabric
Understanding and strengthening key elements of Australia's social and economic fabric to help families and individuals live healthy, productive and fulfilling lives.

C. Frontier Technologies for Building and Transforming Australian Industries

Stimulating the growth of world-class Australian industries using innovative technologies developed from cutting-edge research

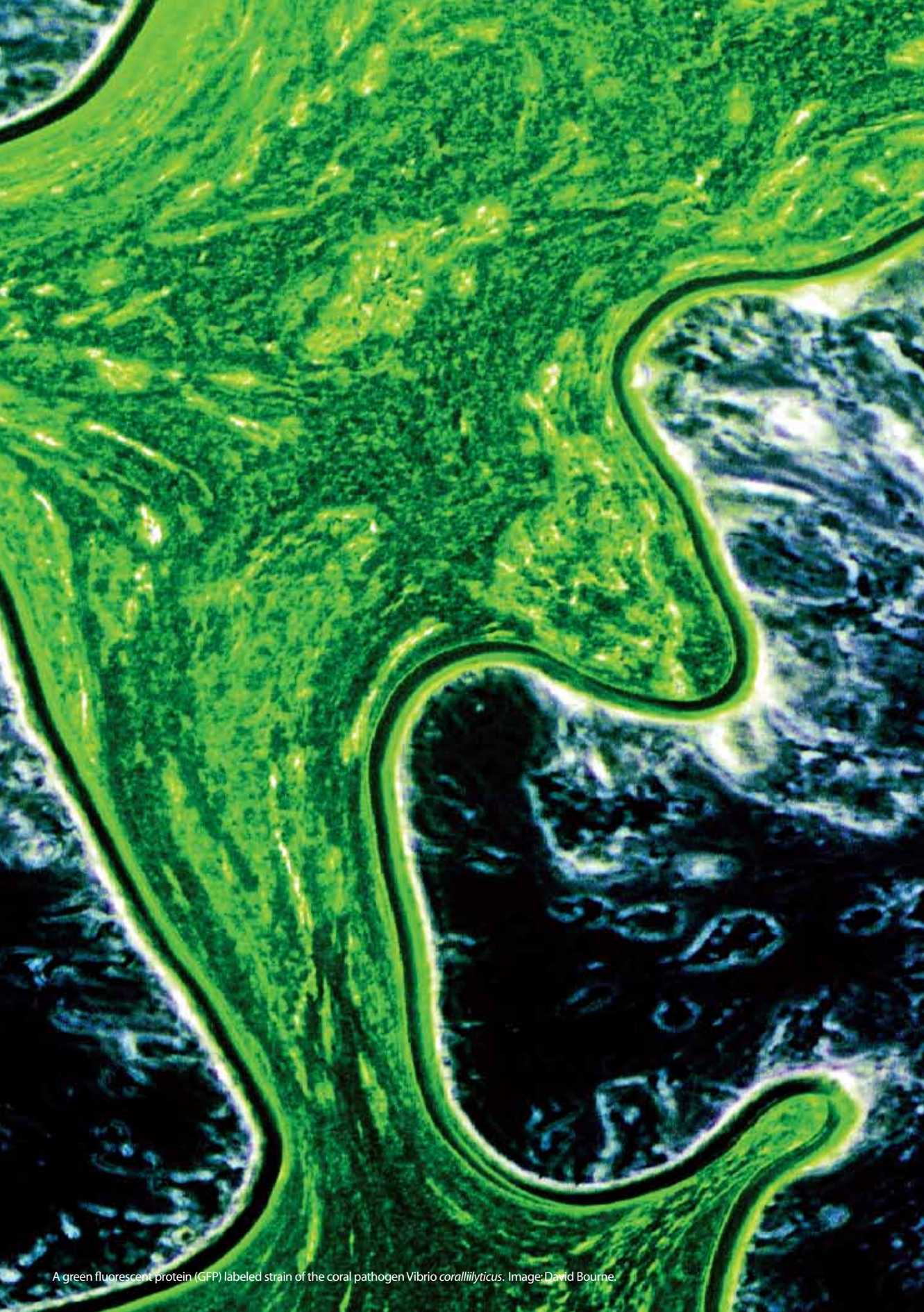
1. Breakthrough science
Better understanding of the fundamental processes that will advance knowledge and facilitate the development of technological innovations.
2. Frontier technologies
Enhanced capacity in frontier technologies to power world-class industries of the future and build on Australia's strengths in research and innovation (examples include nanotechnology, biotechnology, ICT, photonics, genomics/phenomics, and complex systems).
3. Advanced materials
Advanced materials for applications in construction, communications, transport, agriculture and medicine (examples include ceramics, organics, biomaterials, smart material and fabrics, composites, polymers and light metals).
4. Smart information use
Improved data management for existing and new business applications and creative applications for digital technologies (examples include e-finance, interactive systems, multi-platform media, creative industries, digital media creative design, content generation and imaging).
5. Promoting an innovation culture and economy
Maximising Australia's creative and technological capability by understanding the factors conducive to innovation and its acceptance.

D. Safeguarding Australia

Safeguarding Australia from terrorism, crime, invasive diseases and pests, strengthening our understanding of Australia's place in the region and the world and securing our infrastructure, particularly with respect to our digital systems

1. Critical infrastructure
Protecting Australia's critical infrastructure including our financial, energy, communications and transport systems.

2. Understanding our region and the world
Enhancing Australia's capacity to interpret and engage with its regional and global environment through a greater understanding of languages, societies, politics and cultures.
3. Protecting Australia from invasive diseases and pests
Counteract the impact of invasive species through the application of new technologies and by integrating approaches across agencies and jurisdictions.
4. Protecting Australia from terrorism and crime
By promoting a healthy and diverse research and development (R&D) system that anticipates threats and supports core competencies in modern and rapid identification techniques.
5. Transformational defence technologies
Transform military operations for the defence of Australia by providing superior technologies, better information and improved ways of operation.



A green fluorescent protein (GFP) labeled strain of the coral pathogen *Vibrio coralliilyticus*. Image: David Bourne.

Appendix 2.

National Innovation Priorities

The following is an excerpt from the Government's innovation policy agenda released in May 2009: *Powering Ideas: An Innovation Agenda for the 21st Century*. The review of the Innovation Policy Agenda to 2020 can be found at: <http://www.innovation.gov.au/Innovationreview/Pages/home.aspx>

Priority 1: Public research funding supports high-quality research that addresses national challenges and opens up new opportunities.

The Australian Government's ambition is to increase the number of research groups performing at world-class levels, as measured by international performance benchmarks. Investments in public sector research will continue to be guided by the National Research Priorities, which will be updated periodically to reflect changing circumstances.

Priority 2: Australia has a strong base of skilled researchers to support the national research effort in both the public and private sectors.

Skilled people are the single most important prerequisite for successful innovation. The Australian Government's objective is to significantly increase the number of students completing higher degrees by research over the next decade.

Priority 3: The innovation system fosters industries of the future, securing value from the commercialisation of Australian research and development.

The Australian Government rejects the proposition that Australia is a technology-taker, and that policy-makers should not be concerned about the capacity of Australian companies to develop new-to-the-world innovations. It aims to see a continuing increase in the number of businesses investing in R&D.

Priority 4: More effective dissemination of new technologies, processes, and ideas increases innovation across the economy, with a particular focus on small and medium-sized enterprises.

The Australian Government's goal is to achieve a 25 percent increase in the proportion of businesses engaging in innovation over

the next decade. This would bring Australia up to the present European average and – depending on what other countries do – place us in the top third globally.

Priority 5: The innovation system encourages a culture of collaboration within the research sector and between researchers and industry.

Australia has a poor record of collaboration between businesses, between businesses and researchers, and between research agencies. The Australian Government's ambition is to double the level of collaboration between Australian businesses, universities and publicly-funded research agencies over the next decade.

Priority 6: Australian researchers and businesses are involved in more international collaborations on research and development.

Australia produces 3 percent of the world's formal research. Our capacity to innovate depends very much on how effectively we harness and apply the other 97 percent. The Australian Government has therefore adopted the long-term aim of increasing international collaboration in research by Australian universities.

Priority 7: The public and community sectors work with others in the innovation system to improve policy development and service delivery.

Public and community sector innovation brings new and better services to individuals and families. By increasing efficiency, it can also boost national productivity.

Appendix 3. Acronyms and Abbreviations

AARNET	Australian Academic and Research Network
ACFR	Australian Centre for Field Robotics, Sydney University
AMPTO	Association of Marine Park Tourism Operators
ANU	Australian National University
ARC	Australian Research Council
ATSEF	Arafura and Timor Seas Experts Forum
ATRF	Arafura Timor Research Facility
BOM	Bureau of Meteorology
CDU	Charles Darwin University
CERF	Commonwealth Environmental Research Facilities
CoML	Census of Marine Life
CMMG	Centre for Marine Microbiology and Genetics
COTS	Crown-of-thorns starfish
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Department of Environment and Conservation, Western Australia
DCCEE	Department of Climate Change and Energy Efficiency, Australian Government
DEEDI	Department of Employment, Economic Development and Innovation, Queensland
DERM	Department of Environment and Resource Management, Queensland
DIISRTE	Department of Industry, Innovation, Science, Research and Tertiary Education
DSEWPaC	Department of Environment, Water, Populations and Communities, Australian Gov't
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
EPBC	Environment Protection and Biodiversity Conservation Act 1999
FRDC	Fisheries Research and Development Corporation
GBRMPA	Great Barrier Reef Marine Park Authority
GA	Geoscience Australia
GBRWHA	Great Barrier Reef World Heritage Area
IMOS	Integrated Marine Observing System
JCU	James Cook University
LTMP	Long-term Monitoring Program, AIMS
MPA	Marine Protected Area
MTSRF	Marine and Tropical Sciences Research Facility



NAMRA	North Australia Marine Research Alliance
NCRIS	National Collaborative Research Infrastructure Strategy
NERP	National Environmental Research Program
NGO	Non-government organisation
NOAA	US National Oceanic and Atmospheric Administration
QM	Queensland Museum
RWQPP	Reef Water Quality Protection Plan (Reef Plan)
SRRP	Scott Reef Research Project
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Program
UQ	University of Queensland
UWA	University of Western Australia
WAMSI	Western Australian Marine Science Institution