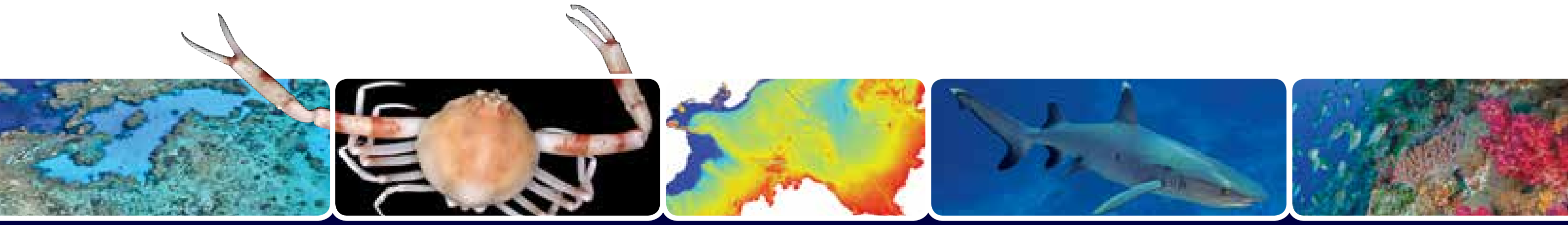
National Environmental Research Program

MARINE BIODIVERSITY hub



JUNE 2015

2011–2015 FINAL REPORT

A national research collaboration delivering marine biodiversity knowledge to the Australian Government

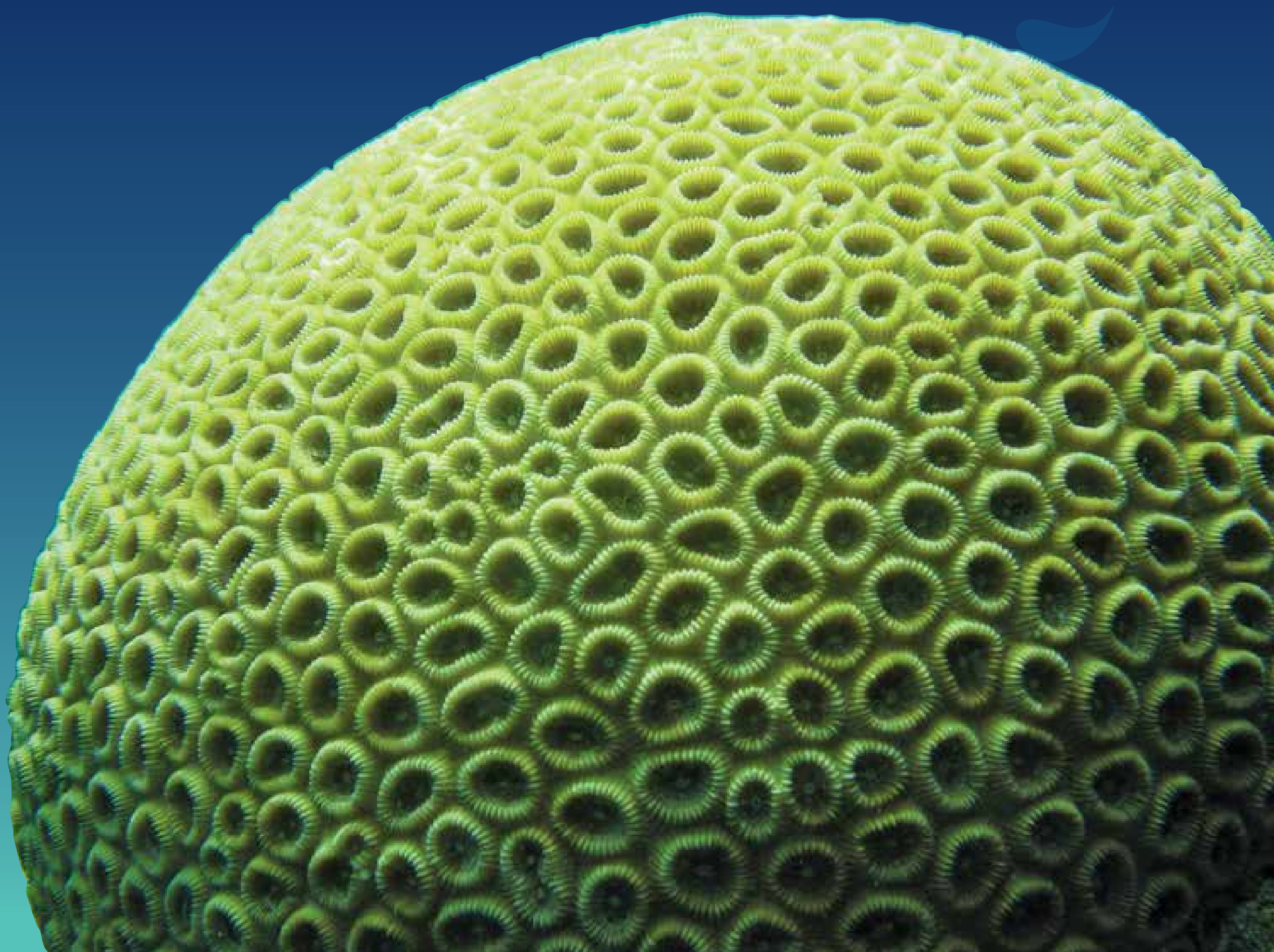


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IMAGE: William White, CSIRO

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FRONT COVER: **A hard coral in 10–20 m depth reef habitat at the Houtman Abrolhos Islands.** Image: Reef Life Survey

Contents

IMAGE: Matt Curnock

IMAGE: Geoscience Australia

Ian Cresswell

Chairman's foreword

The Marine Biodiversity Hub has come a long way since five national research partners were successful in their bid under the Commonwealth Environmental Research Fund (CERF) in 2007.

In 2011, the five partners expanded to seven and were again successful in their bid under the National Environmental Research Program (NERP) which is reported on here. More recently, the now nine partners received funding under the National Environmental Science Program (NESP). The expansion of the Hub, and its success in securing funding in a competitive environment, is testament to its increasing national scope and its alignment with the Department of the Environment to deliver research that supports evidence-based decision making.

As chair of the steering committee for the past eight years, I can attest that it has been an interesting journey. By facilitating collaboration, the Hub has significantly increased the impact of Australia's major marine research partners, and improved the delivery of scientific information to help understand and solve national issues. Starting with the CERF Marine Biodiversity Hub, the partners have developed a long-term strategic portfolio to reach many stakeholders, as well as delivering directly to the Department of the Environment to support the design and planning of the Commonwealth Marine Reserves network. Learning to work more effectively with the Department and stakeholders has been a key outcome of the Hub.

Increased impact through collaboration with the Department was the *raison d'etre* for the NERP Marine Biodiversity Hub. The Hub research was better aligned to deliver directly to support the Department's evidence-based decision making. Two new partners joined the Hub to increase our impact in north and north-western Australia, and to start what has become a highly successful development of research supporting threatened species recovery plans. The NERP Hub has strived to understand how to best provide the right information to individual managers in the Department, as well as to associated agencies and industries. This work is ongoing and has begun a journey toward fundamental change in the way researchers design, conduct and deliver research for greater impact on national decisions.

It has been a fascinating and rewarding experience for me to help set that direction at the steering committee, and to support this growth in the research partnership and the evolving relationship of the partners with the Department and other stakeholders. I have been fortunate to have steering committee members able to leave individual interests at the door and work together to grow the research partnership. I thank the many steering committee members for their inputs during the past eight years and wish the new NESP Marine Biodiversity Hub success under the new chairperson, Peter Cochrane. I will continue to take a keen interest in how the Marine Biodiversity Hub evolves its relationship with the Department and stakeholders and in doing so fundamentally changes the way that research is developed and delivered to guide the major marine environmental challenges facing Australia.

The Marine Biodiversity Hub Steering Committee met formally twice each year. Its membership comprised an independent chairman and representatives from each of the partner agencies, the National Environmental Research Program, the Department of the Environment and stakeholder groups.

Steering Commitee

CHAIR Ian Cresswell

HUB EXECUTIVE
Nic Bax (Director)
Paul Hedge, Vicki Randell

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John Gunn, Jamie Oliver

Charles Darwin University
Andrew Campbell

CSIRO
David Smith

Geoscience Australia
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University of Western Australia
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Department of the Environment
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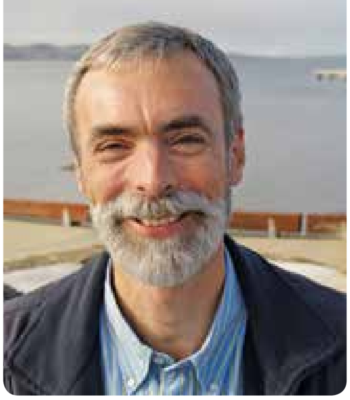


Nic Bax

Director's overview

The overall objective for the NERP Marine Biodiversity Hub was to '*provide scientific information and advice that will support (the Department of the Environment) in decision making in the marine environment, specifically to:*

- *implement and monitor marine bioregional plans;*
- *develop the National Representative System of Marine Protected Areas (NRSMPA);*
- *support the information needs of the Environmental Resources information Network (ERIN) and Approvals and Wildlife Division (AWD); and*
- *provide key baseline information for the Heritage Division*'.

For four years, the seven NERP Marine Biodiversity Hub partners have worked closely with departmental officers, adjusting research and deliverables to suit a changing policy environment. The research was coordinated by a Research Leadership Team comprised of theme and project leaders, and representatives from all partners. This ensured the adoption of research advances, such as the application by the Regional Biodiversity Discovery Theme of survey design approaches developed in the Monitoring Theme.

Stakeholder and partner representatives on the Hub Steering Committee oversaw the program and provided guidance to the Director, and many collaborators have been integral to the research. Infrastructure provided through the Integrated Marine Observing System (IMOS) was vital to the success of projects investigating seabed condition, while threatened species projects depended on the infrastructure and personnel resources of Northern Territory Fisheries, the New South Wales Department of Primary Industries, the New South Wales Office of Environment and Heritage, and the Department of Fisheries Western Australia, in addition to IMOS. Other collaborators are listed on page 80.

To ensure relevant and appropriate research outputs, research leaders and especially the Hub Director and Knowledge Broker endeavoured to understand the decision making challenges that face departmental officers, and the associated information needs. A peer-reviewed journal paper, essential to scientific development, is of little direct use to a manager required to make rapid decisions, unless the data have also been provided in a form suitable for the internal information system. Consequently, the Hub Knowledge Broker developed communication products useful to departmental officers and increased the managers' capacity to use them. When the *Plan for a Cleaner Environment* was released in October 2013 setting the new government's environmental management strategy, we mapped the Hub's ongoing research to this new strategy (see figure opposite), and were encouraged to see that our research portfolio still met Australia's marine biodiversity research needs.

Scientists still frequently believe that good science will be adopted and are surprised when frontline managers have not used the latest available scientific information. This is because we often focus on what science can deliver, rather than what the customer wants. But what does the customer want? A clear summary of Departmental research priorities can be difficult to find. This is perhaps understandable as we are asking managers to step into our shoes and show us what research they would find valuable. What if, instead, we ask what

ABOVE: **Marine Biodiversity Hub surveys have provided baseline descriptions to support future monitoring of CMRs.**

Drivers of research	Focus areas of research	Impact of research
Commonwealth Marine Reserve network (CMRs) management	> Collating marine survey and pressure data for CMRs > New surveys of selected CMRs > National capacity for sustained data collection in CMRs	> Performance indicators for managing CMRs > National data catalogue for CMRs > Baseline surveys for the Flinders and Oceanic Shoals CMRs > Enhanced national capacity for sustained data collection > Blueprint for monitoring
Marine Bioregional Plan implementation	> Collating survey and pressure data for KEFs > New surveys of selected KEFs > Supporting evidence-based decision-making	> National data catalogue for KEFs > Baseline surveys for selected KEFs > Blueprint for monitoring EEZ ecosystems > Tools for evidence-based decision-making > Data collection standards for multiple sectors and jurisdictions
Reef 2050	> Aligning management priorities with existing monitoring > Integrating monitoring with management	> GBRWHA integrated monitoring framework > Guidance to integrate monitoring for other marine regions or programs
Recovery of EPBC listed species	> Status trends and habitat use of threatened species	> More targeted and effective implementation of recovery plans > Evidence base for recovery of threatened sharks

is valuable in their daily routines? What decisions are made and what data are routinely used? We have had good results using this approach. We have collaborated with the Department to develop a blueprint for marine ecosystem health monitoring in Commonwealth waters. We have worked with ERIN and marine managers in the Department to map where and how data are used to support decision making. We have also led the development of an integrated monitoring framework for the Great Barrier Reef World Heritage Area. This intensive engagement driven by specific questions asked by departmental officers has required substantial effort and resources, but has been instrumental in increasing the impact of research outputs.

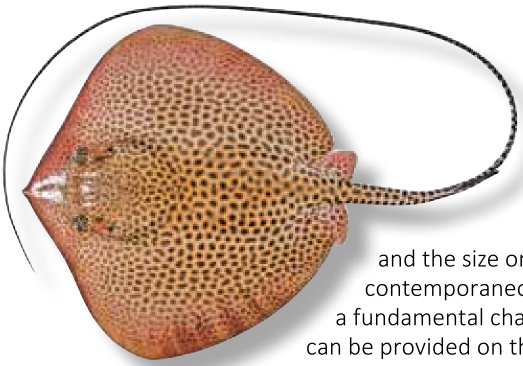
Adapting to changing policies

The Hub's efforts to help the Department *implement and monitor marine bioregional plans* met with mixed success. Ironically, some of the research areas most tightly linked to departmental decision making – such as marine implementation of the revised offsets policy – have been challenged by a changing policy environment. This is a reminder that if our goal is to influence decision making, we cannot assume that Department and stakeholder goals and objectives will remain constant. Other areas have met with much more direct success.

We have improved the understanding of conservation values identified in marine bioregional plans, including Commonwealth marine reserves (CMRs) and Key Ecological Features (KEFs). We have also cultivated the collaborations and developed the standardised approaches required to monitor CMRs and marine ecosystem health, and contribute to State of the Environment reporting. A marine blueprint is being developed with the Department to understand our capability to monitor status and trends of marine biodiversity in deep waters, and the opportunities to extend that capability. This will provide a foundation for integrating existing and new monitoring programs to cost-effectively support planning, regulation and management. It complements the integrated monitoring framework developed in collaboration with two other Hubs, the Great Barrier Reef Marine Park Authority and the Queensland Government that has been incorporated into the *REEF 2050 Long-Term Sustainability Plan*.

A landscape approach to marine management identified the areas used by multiple vulnerable shark species. Further management attention in such areas could benefit multiple species while reducing the impact on fisheries, compared with a species-by-species approach. A second approach used predictions of the distributions and commercial uses of benthic habitats in South-east Australia to estimate the impact of alternative management tools (such as fisheries closures and CMRs) on habitat destruction and recovery. The tools and techniques developed in these landscape projects are being advanced outside the Hub to support commercial fisheries management.

Threatened species research was initially focussed on projects that would enable recovery plans to be implemented more cost effectively. Euryhaline elasmobranchs were selected to examine whether new genetic and telemetry approaches effectively support decision-making and appraisal of recovery plans. Early success with this approach has led to its extension to White Sharks and Grey Nurse Sharks, and is providing the first estimates of adult population size.



Ongoing developments may soon enable measures of adult population size, and the size one generation ago, all from contemporaneous samples. This promises a fundamental change in the information that can be provided on these threatened species. Our research capability built on earlier fisheries research and supported the Department in decision-making under the *Environment Protection and Biodiversity Act 1999*. It supported the development and implementation of recovery plans, the international convention in trade on endangered species and the evaluation of potential impacts of proposed activities and developments.

Hub research has helped the Department to *develop the NRSMPA*, providing baseline descriptions for CMRs (Oceanic Shoals, Flinders, Freycinet, Tasman Fracture, Geographe, and Coral Sea) to support future monitoring. Robust survey designs were developed that will withstand both funding and oceanic conditions. Social and economic studies are helping to identify how the public identifies with and values the marine environment and marine protected areas, and how different forms of communication and information affect perceptions of management options. We had less success in working with the Department to operationalise management objectives for the CMR network, partly because the Department needed to focus on a changing policy environment that included the CMR Review. Adding to this was the challenge of prioritising management objectives for a representative network covering more than a third of Australia's Exclusive Economic Zone, from high tropical species richness in the north to high endemism in the south.

Improving data access

Data discovery and access has improved during the course of the Hub, contributing to the objective to *support the information needs of ERIN and AWD* (now Environmental Assessment and Compliance). We have worked with the Australian Ocean Data Network (AODN), the Atlas of Living Australia and partners and collaborators to make data available soon after collection. At the same time we have helped to increase the relevance of these data portals to environmental managers and researchers by enabling searches on conservation values including CMRs and KEFs. National maps of pressures and how they have changed over time (aggregated to match the State of the Environment reporting cycle) are now available through the AODN and will be an important input to State of the Environment 2016. We have also developed a search tool that extracts previous survey information relevant to monitoring CMRs and the use of KEFs for monitoring marine ecosystem health. We have worked with ERIN to identify marine policy and management decisions being made in the Department, and the supporting data portals and processes. Further work remains in this area, including through the National Plan for Environmental Information, but we are confident that we are developing a deeper understanding of the Department's information needs. Scientists' information needs, including longer term data archival, are also being met through existing national research data infrastructure.

In *providing key baseline information for the Heritage Division*, Hub scientists have developed new national datasets and classifications to identify and assess areas of natural heritage. An accurate map and classification of Australia's 750 marine canyons (many previously unrecognised) will identify canyons that may have higher biodiversity value. New national and global biogeographies provide the basis for moving beyond the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 4.0). New genetic analyses of existing museum samples indicate that movements of the Earth's tectonic plates contributed to the speciation of marine fauna.

The Hub would not have achieved the successes that it has without the many dedicated researchers in partner institutions, or without our many collaborators. It is a pleasure for me to recognise the many and diverse inputs from such a talented and creative group of people. Finally, I would like to take the opportunity to thank the Steering Committee which has unfailingly been available to provide sound guidance that has improved the outcomes of the NERP Hub and laid the foundations for the NESP Marine Biodiversity Hub.

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Knowledge brokering

Collaborative research conducted through the NERP Marine Biodiversity Hub provided evidence and advice to support management decisions relating to the conservation values of Australia's marine environment.

Knowledge brokering was integral to this process, ensuring projects were appropriately designed and scoped to meet the needs of end-users, in particular the Department of the Environment, and that results were provided in a format that would be used by decision makers.

Approach

A knowledge broker was appointed to help develop and exchange knowledge between scientists and policy makers. The knowledge broker, also the Deputy Director of the Hub, worked closely with the Director and Research Leadership Team. A broad group of scientists, policy makers and communicators supported the exchange of knowledge, including the Hub's Steering Committee, project leaders, senior executives, policy officers, marine reserve managers, technicians and data managers.

Knowledge brokering under the NERP built on previous success with the Commonwealth Environment Research Facility (CERF) Marine Biodiversity Hub. Under the CERF program, knowledge brokering activities generally focused on informing and engaging scientists and policy makers so that scientific outputs could be understood and used. Under NERP, we extended this approach to inform, engage, collaborate and build capacity, regularly revisiting important areas to ensure that the outcomes remained integral to Departmental activities. The five stages of knowledge brokering under NERP were:

- scoping and refining research projects in collaboration with the Department;
- describing research outputs and indicators of impact to identify key users;
- communicating progress toward outputs to maintain engagement;
- delivery of outputs in an agreed format; and
- evaluating impacts on Departmental activities.

Understanding the nature of research projects, the policy setting, the people and their capacity for engagement was important. Research drivers focused on adaptive management and the monitoring and evaluation of conservation value, and marine reserves were a focus of collaboration, capacity building and, in some cases, co-production of project outputs. Policy drivers were Marine Bioregional Planning, including managing the CMR network, species recovery plans and REEF 2050. The marine monitoring blueprint and the Great Barrier Reef World Heritage Area monitoring framework are examples of products that tailored the best available science to meet policy objectives. Knowledge brokering also supported project leaders to forge relationships with end-users.

Lessons learned

Marine Biodiversity Hub scientists and end-users, particularly policy makers and managers from the Department, embraced and participated in knowledge brokering. This was most evident in their commitment to plan and

BELOW: **Marine reserves were a focus of collaboration and capacity building during the NERP Marine Biodiversity Hub.** Images: Reef Life Survey (left) and University of Western Australia

Knowledge brokering

Knowledge brokering

implement strategies designed to inform, engage, collaborate and build capacity for applied marine research. The great example of this was the scoping and progressing of research to support plans for the recovery of listed species. In these instances, well structured policy problems, clearly defined data and information needs, and established relationships between researchers and policy makers, enabled effective engagement and knowledge exchange.

Considerable capacity was built in the area of marine monitoring, particularly in terms of understanding how policy and research are central to developing a shared language and logic for monitoring and environmental reporting. This is a challenging arena in which the interests and resources of policy makers and researchers converge. Ongoing knowledge brokering will enhance the contribution of monitoring to evidence-based decision making.

The knowledge broker played an important role in interpreting the Australian Government's environmental policies and conservation values for the marine research community. This was particularly important for projects operating in an ambiguous, broad, or evolving policy context, such as marine offsets. Managing sensitivities and expectations for research in social and economic disciplines was another challenging area (also experienced during the CERF Hub). The knowledge broker also maintained the momentum of research collaborations affected by restructures and staff changes in the Department, and identified opportunities to expand agreed research outputs to meet the needs of end users.

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Building a framework for the world's largest living structure

Establishing an integrated monitoring framework for the Great Barrier Reef World Heritage Area (GBRWHA) presented a significant knowledge brokering challenge amid tight timeframes set to meet processes under the *Environment Protection Biodiversity Act 1999*. Developing a more strategic approach to reef monitoring involved collating a wealth of information on management needs and 65 existing monitoring programs, and harmonising the needs and views of diverse specialists and stakeholders in the complex setting of adaptive management.

Policy makers, scientists, and data and natural resource managers helped to define and prioritise steps towards integrating management and monitoring approaches, and distilled this into practical guidance applicable in any coastal or marine region. The guidance was subsequently applied to the GBRWHA to develop an integrated monitoring framework tailored for GBR managers. This provided the basis for further collaborative efforts to build the monitoring program (see story on page 61).

Stakeholder commitment to participation has been vital to successful knowledge brokering in this project and has involved developing a shared language and logic for integrating monitoring, including the identification of key management and science inputs, essential monitoring functions and options for engaging experts and stakeholders.

The monitoring framework contributed to the strategic assessment of the World Heritage Area in 2014 and is guiding development of a reef-wide integrated monitoring and reporting program to review the success of the *Reef 2050 Long-Term Sustainability Plan* (draft released for public comment in September 2014). It will build on and coordinate existing monitoring and reporting activities and will be linked to the outcomes and targets identified in the plan.

ABOVE: **The Great Barrier Reef World Heritage Area.** Image: Great Barrier Reef Marine Park Authority

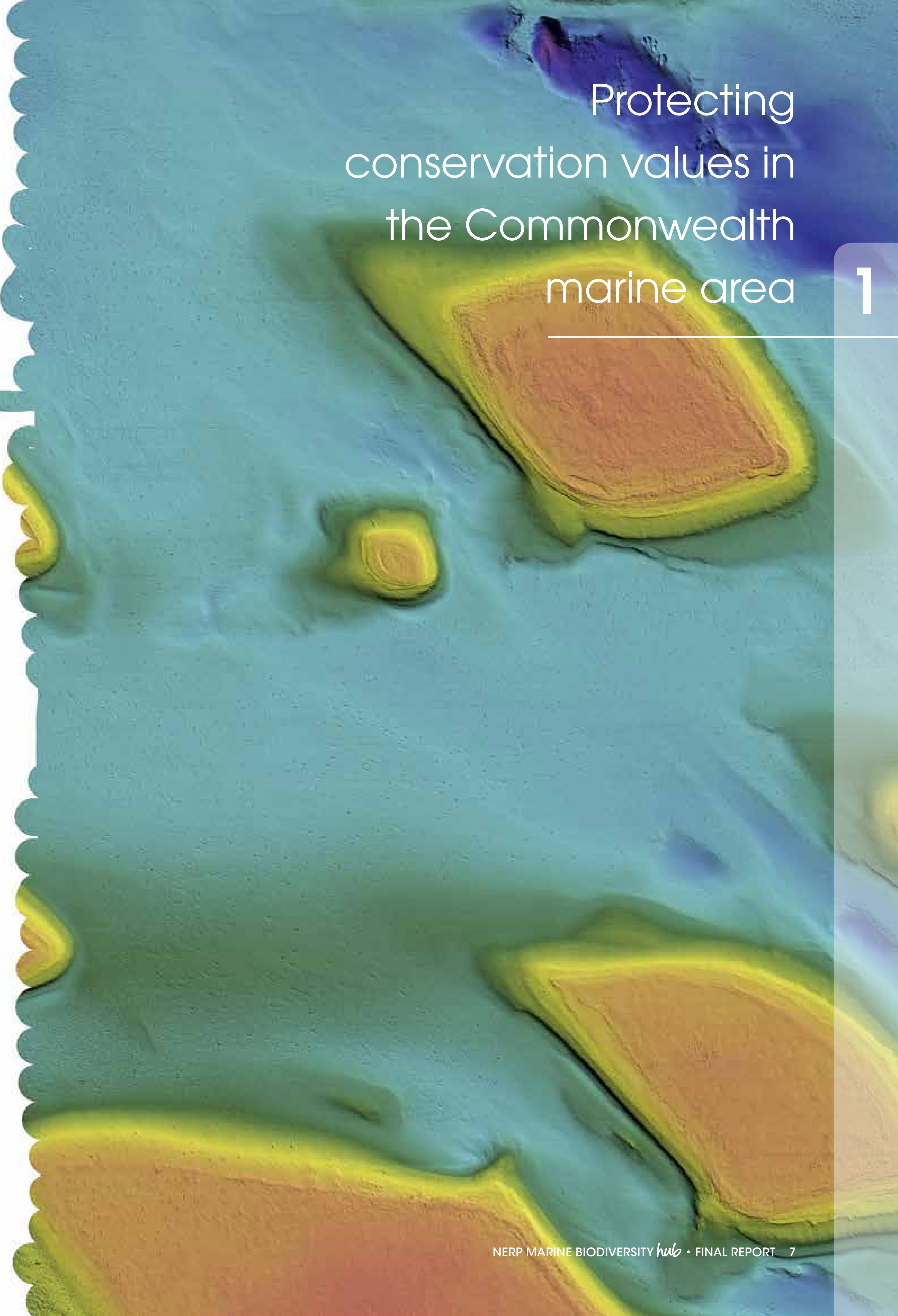


IMAGE: Geoscience Australia

1 Protecting conservation values in the Commonwealth marine area

The need

Commonwealth marine areas are protected as a matter of national environmental significance under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*).

The Australian Government has developed marine bioregional plans for five Commonwealth marine planning areas to help government and industry manage and protect the marine environment. The plans describe the marine environment and conservation values of each marine region, set broad biodiversity objectives, and identify regional priorities, strategies and related actions.

Conservation values are defined in the plans as species or places that are listed under the *EPBC Act*, (such as threatened species or heritage areas), or Key Ecological Features considered important for a region's biodiversity or ecosystem function and integrity. Marine Biodiversity Hub research on these conservation values is covered in this section of the report. Hub research on listed species is covered in Section 2, and research on Commonwealth marine reserves and the Great Barrier Reef World Heritage Area is covered in Section 3.

Research was designed to contribute to the following strategies identified in marine bioregional plans:

- **provide relevant, accessible and evidence-based information to support decision-making with respect to development proposals that come under the jurisdiction of the *EPBC Act*;**
- **increase collaboration with relevant industries to improve understanding of the impacts of anthropogenic disturbance and address the cumulative effects on the region's key ecological features and protected species; and**
- **improve monitoring, evaluation and reporting on ecosystem health in the marine environment.**

Responding to the need

An important research focus was to make better use of existing physical and biological data to better understand biodiversity in the Commonwealth marine area. Museum collections were reinterpreted to characterise the spatial structure of marine habitats and communities at national scales and to identify prehistoric processes that influence contemporary biodiversity patterns. Further data were used to identify habitats inside and outside CMRs that support multiple species of vulnerable elasmobranchs and may benefit from refinements to management. The impact of fisheries and biodiversity conservation management interventions in the past three decades on the predicted state of benthic communities was also investigated. Surveys were used to gather information about how the public values the marine environment, existing data were collated on environmental pressures and their potential for cumulative impact.

Hub scientists worked to improve monitoring and reporting on ecosystem health through an enhanced understanding of KEFs and by extending Australia's capabilities to collect and analyse relevant biological data in deep water environments. Finally, this new knowledge and capability was combined with an extensive review of existing data relevant to KEFs as input to a blueprint for monitoring ecosystem health. This was developed in concert with the Australian Government Department of the Environment and other stakeholders.

IMAGE: CSIRO

Canyons: identifying connectivity patterns for management

Submarine canyons are areas of high biological productivity and aggregating marine life, from deep-sea corals to foraging blue whales.

A better understanding of how the physical, biological and ecological characteristics of canyons are shaped on a national scale would help to prioritise their conservation and sustainable use. This project generated a better understanding of how submarine canyons may influence biodiversity patterns across marine regions, including within and between CMRs. It mapped and measured Australia's submarine canyons, classified their structure, and determined how they are linked: to each other, to the deep ocean, and to the continental shelf. A central question was whether all canyons functioned similarly with respect to the physical processes that influence biodiversity.

Connectivity modelling enabled the strength and direction of population links between canyons to be examined: for example, whether the exchange is upstream, downstream or both ways. The degree to which an area contributes to other areas is its source capacity; the degree to which it receives from other locations is its sink capacity. Canyons with high sink capacity encourage larval settlement, and are likely to have high resilience due to their strong connectivity with larval sources. Canyons with a high source capacity can boost ecological resilience by exporting larvae to other locations.

Approach

Tools and methods were developed to examine the relationships between canyons, large-scale ocean currents and biodiversity values. New bathymetric maps were generated, and indicators of ocean productivity across the Exclusive Economic Zone (EEZ) were derived from time-series maps of sea-surface properties (temperature, chlorophyll-a, turbidity). Remote sensing techniques were also used to define the spatial and temporal variability of the Leeuwin Current, as a case study for the South-west Marine Region. Spatial statistical methods were used to classify canyon types (such as shelf-incising and slope-confined) and fish distribution patterns, to examine relationships between canyons, canyon types, and other seabed features, and to identify areas of conservation priority.

NATIONAL MAP OF SUBMARINE CANYONS IN RELATION TO COMMONWEALTH MARINE RESERVES

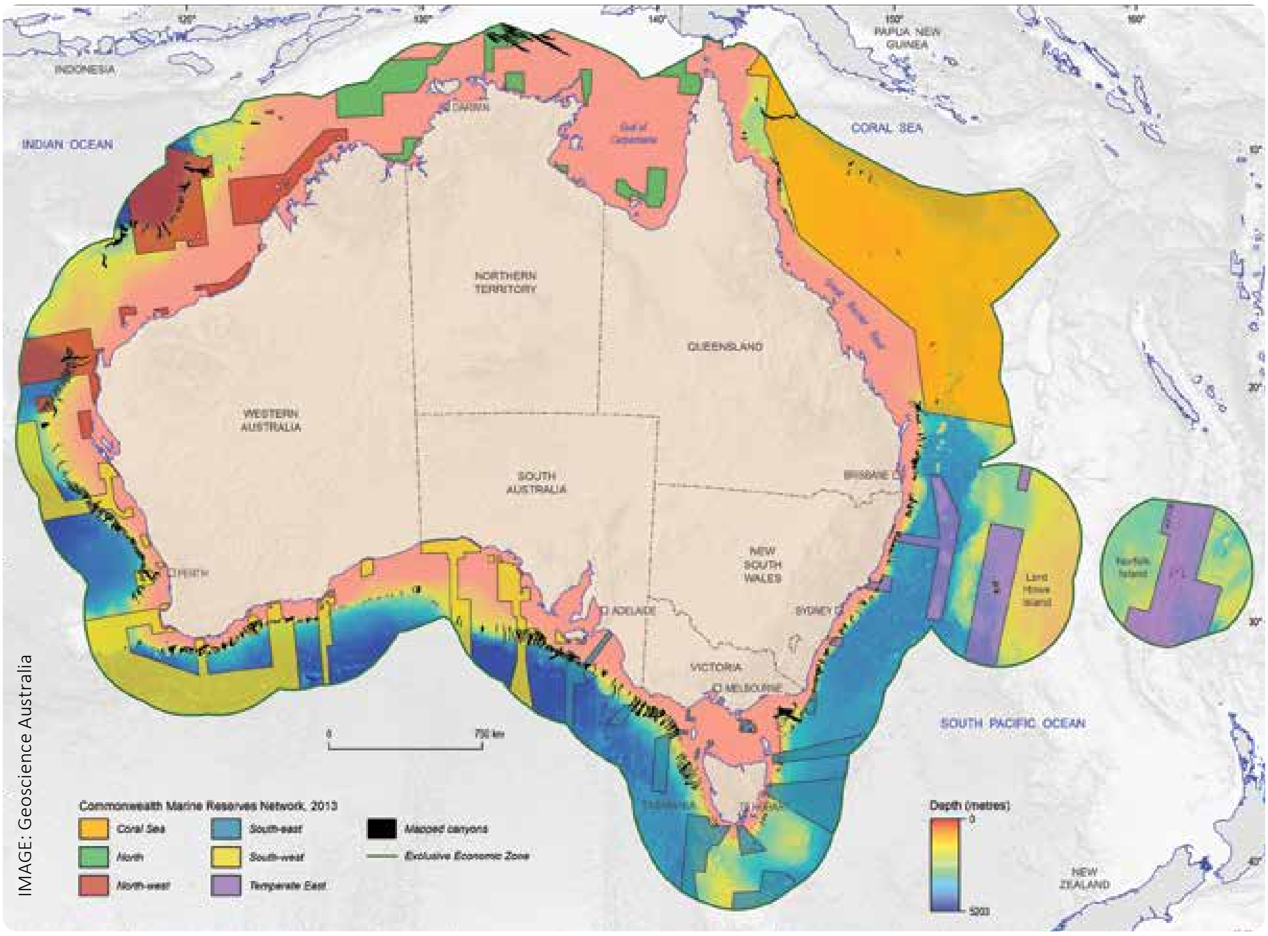
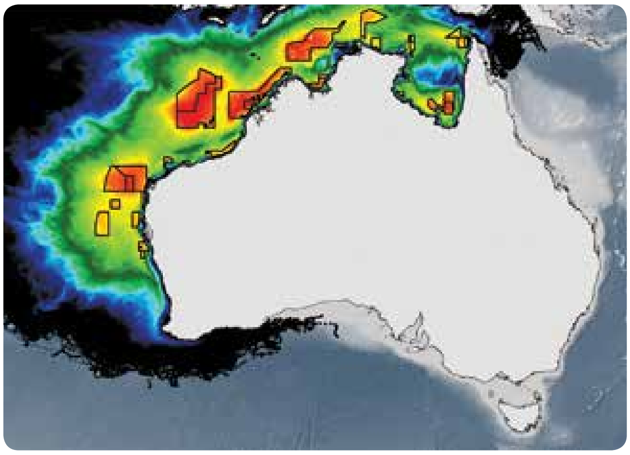


IMAGE: Geoscience Australia

A new acoustic methodology that can consistently differentiate hard from soft substrate was developed to classify potential benthic habitats associated with canyons. A uniform scoring method was used to classify epibenthic fauna in these habitats from seafloor video imagery (656,649 records from 12 voyages). Shelf-incising canyons were analysed and their habitat types and fauna compared to the surrounding slope, with the expectation that relatively high proportions of hard substrates and associated fauna would be found where canyons incise the shelf edge.

An individual-based dispersal model (see story on page 12) was used to simulate the movement of marine larvae from the coastline to the 200 nautical mile limit of the EEZ (excluding external territories). Their connectivity – the degree of exchange between two different populations or areas – was measured at local (canyon), regional and continental scales according to the scale of larval transportation. The model was used in case studies exploring the source/sink capacity of canyons in CMRs of the South-west and North-west marine planning regions.



ABOVE: **Simulated dispersal of brittle star larvae originating in north and north-western CMR waters for 2009–2012. Warm colours indicate relatively high larval densities, and cooler colours show areas where lower larval densities are expected.** Image: Geoscience Australia

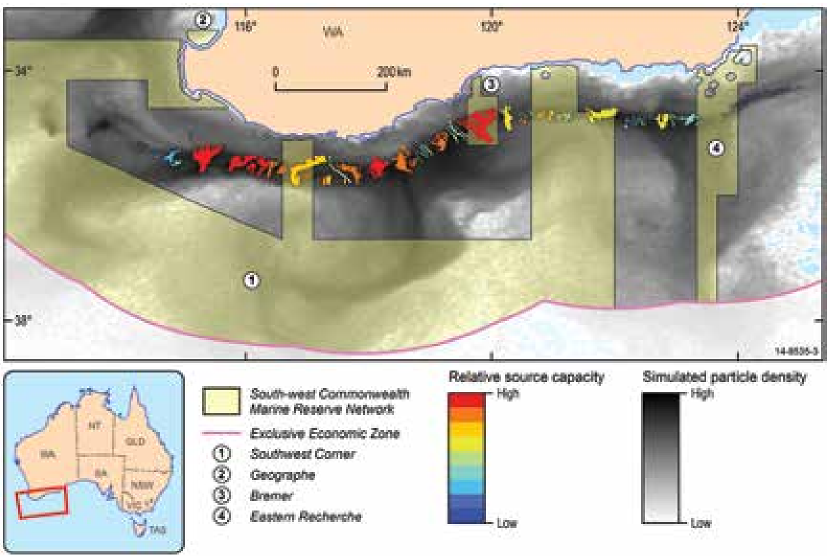
Key findings

More than 750 canyons were mapped across the Australian margin, including Norfolk Island and Cocos Island Territories. This is many more than previously known. Almost 40% of the canyons were in a marine reserve, and of the 29 canyons that were identified as having high biodiversity value, 24 are located in existing Key Ecological Features (KEFs) and CMRs.

Hard ground habitats in the 150-700 m depth range were both infrequent and quite highly variable between canyons for the 60 shelf incising canyons for which data were available. Video imagery showed benthic epifauna abundance to be depth stratified and higher inside canyons. Seabed hardness was an important habitat classifier for a large subset of the fauna. Based on the video imagery, the shelf incising canyons did not support significantly different epibenthic macrofauna when compared to other upper slope hard and soft substrate. Canyon-specific metrics of epifauna biomass and distribution, and finer taxonomic resolution of fauna, appear to be needed to resolve biodiversity distribution patterns within and outside canyons. This will be necessary for any prioritisation of individual features or areas for management attention.

A study of connectivity in the South-west Marine Region conducted as part of this project found the Albany Canyons off south-western Australia to be an important sink and source for marine larvae transported eastward by the Leeuwin Current. Twenty-five of the 81 Albany canyons had medium to high sink and source capacity: mostly the larger, topographically complex canyons such as Wilson and Bremer canyons, suggesting that these two canyons may have a larger role in maintaining the

ALBANY CANYONS: CAPACITY TO ACT AS A SOURCE FOR MARINE LARVAE

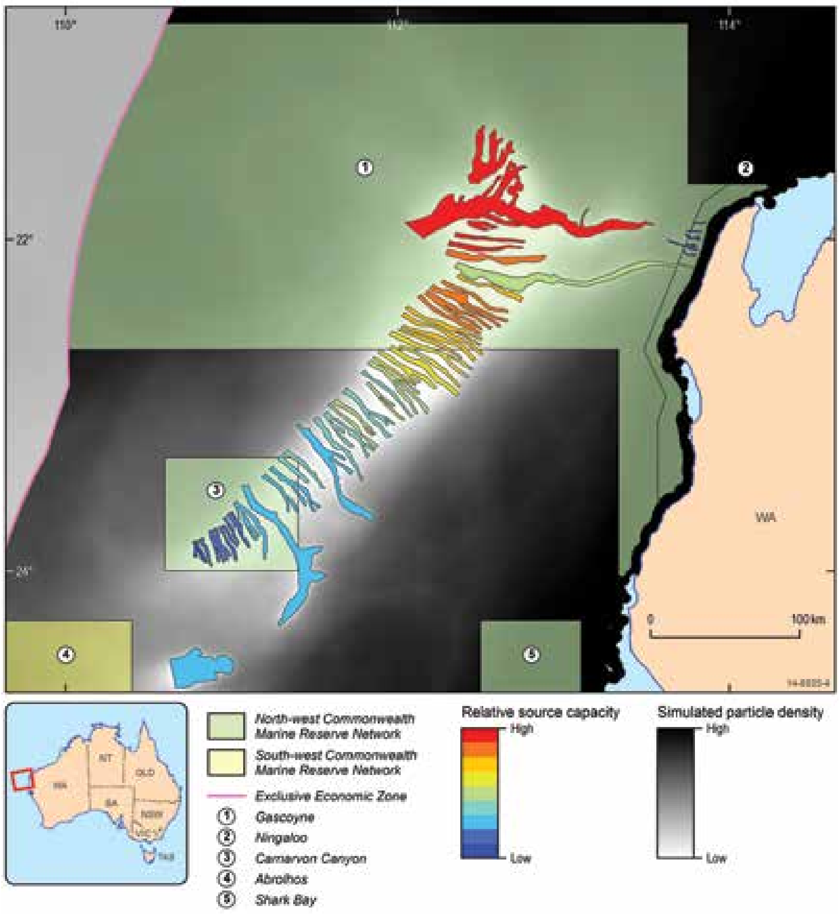


ABOVE: **Albany Canyons showing the capacity for each canyon to act as a source for marine larvae, modelled for larval release across the South-west marine region in 2009 (represented by the grey dispersal cloud).** Image: Geoscience Australia biodiversity of this area than the other canyons. The strong connectivity of these Albany Canyons is driven by the Leeuwin Current and augmented by secondary flows that recirculate the larvae dispersal cloud westward, providing additional opportunity for larval settlement. Smaller canyons to the east, at the downstream end of the current's dispersal path, and outside CMRs, tended to have a low relative sink and source capacity.

The individual-based model also showed that time-series earth observations are effective in mapping the Leeuwin Current and to quantitatively investigate the temporal variability of its oceanographic and geographical characteristics. The findings indicate that the Leeuwin Current has strong seasonal and inter-annual variation in its area of influence and cross-shelf migration. The Leeuwin Current also has a significantly positive influence over the nutrient characteristics of the South-west Marine Region.

A study of canyons in the North-west Marine Region conducted as part of this project focussed on canyons that intersect several CMRs offshore from Cape Range Peninsula (Gascoyne, Carnarvon Canyon and Ningaloo). The connectivity model showed a higher sink and source capacity for canyons in the northern half of the group, with most of those canyons intersecting the Gascoyne CMR. In contrast, canyons within the Carnarvon Canyon CMR had low sink and source capacity for marine larvae. This variability in sink and source capacity across a relatively small area reflects the 'decay' of the dispersal cloud along the direction of the Leeuwin Current and with distance offshore. Similarly, the shelf-incising canyons that intersect Ningaloo CMR have low sink capacity due to their weaker links with the Leeuwin Current.

CAPE RANGE CANYONS: RELATIVE CAPACITY TO ACT AS A SOURCE FOR MARINE LARVAE



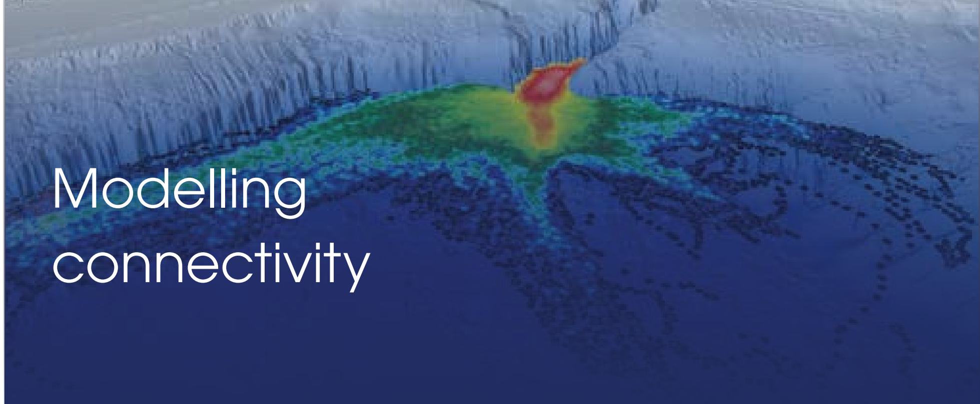
ABOVE: **Cape Range Canyons showing the relative capacity of each canyon to act as a source for marine larvae, modelled for larval release across the North-west marine region for 2009 (represented by the grey dispersal cloud).** Image: Geoscience Australia

New knowledge and opportunities

Datasets and models produced in this project provide a foundation for targeted studies aimed at testing/validating components of the connectivity patterns identified by the dispersal model.

This project is producing a comprehensive assessment of Australian canyons as habitat for benthic and pelagic species. The assessment is using biodiversity surrogates, (such as seafloor rugosity, upwelling strength and current velocity), to classify habitat complexity, productivity and disturbance. Geomorphometrics, (measures of seafloor complexity), such as canyon distribution and seafloor rugosity have an important influence on the movements of large fish predators over macro-ecological scales.

The connectivity model and canyon maps can be used to identify data gaps and priority areas for future observations and sampling, either to reduce uncertainty in lesser known areas such as the North-west Marine Planning Region, or to confirm the presence of locally important biodiversity values inside and outside the CMR network. The modelling can also explore connectivity patterns between marine regions and interdependent geographic regions, and reveal areas that may have a relatively higher role in maintaining the biodiversity of the area. For example, the models predict strong ophiuroid connectivity between the Oceanic Shoals and Kimberley CMRs.



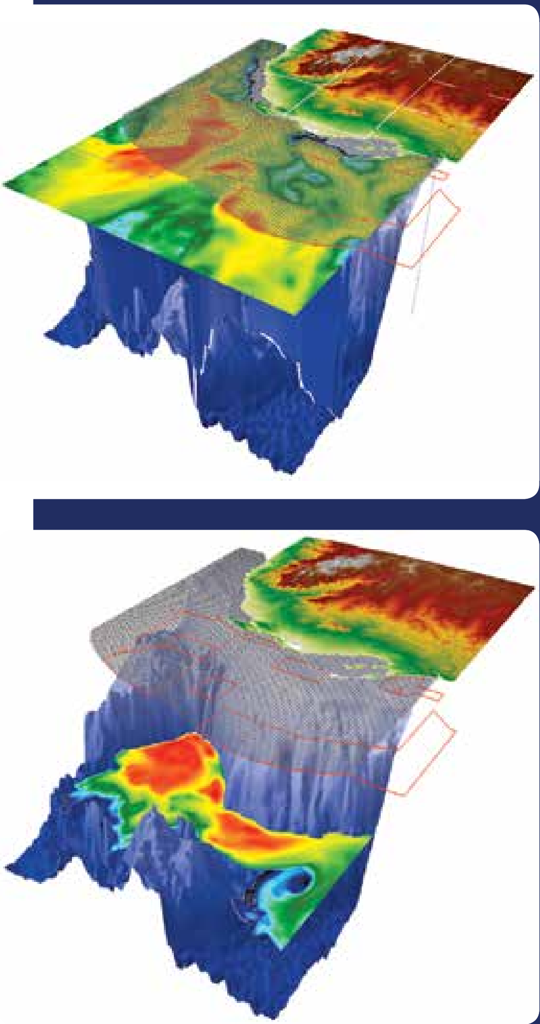
Modelling connectivity

Well-connected populations can ameliorate habitat fragmentation by reaching out to one another during difficult times. Connectivity also lets species reach previously unoccupied changing habitat, and can generate concentrated pockets of diversity through overlap and accumulation.

This study developed an individual-based dispersal model to simulate the movement and connectivity of marine larvae in four dimensions (three-dimensional space over time). The model simulates the interactions of billions of individual larvae with their environment, enabling studies of their collective behaviour.

Three-dimensional ocean currents and larval behaviour are combined in the model to map the expected flow patterns (for a pelagic larval phase of 90 days). Australia's national supercomputer at the Australian National University performs the trillions of calculations required, and the connections it traces can be sliced or grouped by geography (such as canyons, marine reserve, Key Ecological Feature, or volume) and time.

Connectivity modelling can help to guide management decisions by detecting interdependent areas such as clusters of canyons, exchanges between regions, and areas of high 'source' capacity. It can also point to critical links that maintain the resilience of marine systems, and predict the potential spread of invasive species.



ABOVE: Depth slices taken through three-dimensional larval dispersal clouds at the sea surface (upper) and 3000–3500 m water depth (lower) spanning the Gascoyne, Carnarvon and Abrolhos CMRs. Warm colours represent high larval concentrations. Note the broader dispersal at the sea surface and trapping effect of canyons at depth. Image: Geoscience Australia

Outputs and outcomes

The study produced national canyon and Leeuwin Current datasets in GIS format, a time series MODIS dataset in GIS and remote sensing formats, and a national-scale point cloud database of simulated marine larval dispersal. This database is incorporated in the connectivity model, and can be used to determine expected levels of connectivity among user-defined geographic areas and depths (such as CMRs and KEFs).

A nationally consistent map of canyons on the Australian margin, and maps of hard and soft substrate for shelf incising canyons and compiled video annotation data, were also produced. This information can be used to develop a better understanding of how topographic features influence biodiversity patterns in areas such as Ningaloo Reef, and can also be applied in studies of ecosystem processes, such as studies of population connectivity among these features.

Outputs from the connectivity model are publically available and have been applied to a range of resource management challenges: by the Australian Fisheries Management Authority Slope Resource Assessment Group to investigate geographic stocks of Blue Eye Trevalla; by James Cook University to study Wideband Anemonefish; and by the University of Western Australia to study coral dispersal from the Abrolhos Islands. Cross-agency information sharing and collaboration has also covered science-management communication, ocean currents and upwelling processes.

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Improving access to information about fish communities in Commonwealth marine reserves

Under the Integrated Marine and Coastal Regionalisation of Australia (IMCRA v4.0), Australia's marine environment was classified into bioregions that make sense ecologically and are at a scale useful for regional planning.

The bioregions under IMCRA were an important input to Australia's marine bioregional planning program and the subsequent identification of a network of Commonwealth marine reserves. Fish distribution data were an important part of IMCRA's classification process.

This project has improved the accessibility and utility of existing and new information about fish distributions for environmental managers, scientists and the general public. This is expected to support the understanding of biodiversity values in Commonwealth marine reserves, in Key Ecological Features (KEFs) and across broader Commonwealth waters.

Approach

NERP Marine Biodiversity Hub scientists worked with the *Atlas of Living Australia* (ALA) to compile, centralise and streamline access to existing fish data derived from field research and museum collections. The project drew on an improved knowledge of historic and present-day processes that relate to marine fish distributions (developed in associated research). The resulting data extend the knowledge-base to more than 4500 species of marine fishes. Data are being made available through the FishMap search interface previously developed by CSIRO and the ALA.

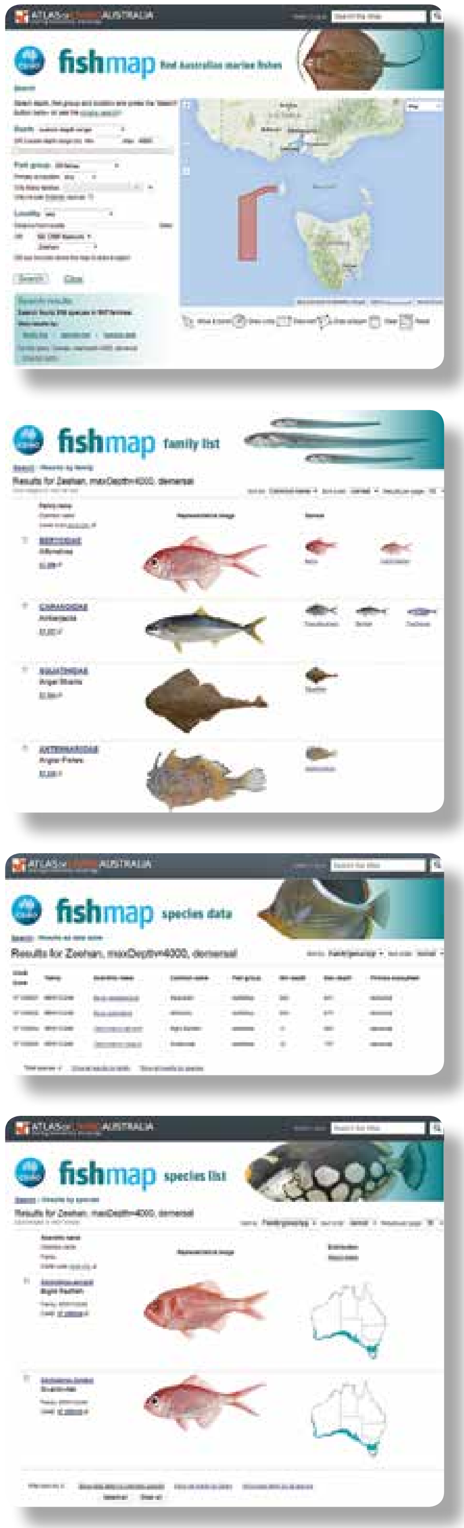
Outputs, outcomes and opportunities

FishMap generates customised, illustrated lists of fishes by area, depth, family or ecosystem that can be used for research, planning, management, fisheries, conservation, recreation and citizen science. It is the only resource of its kind in the world that covers virtually all species of marine fish found in the marine waters of an entire continent.

The service is being revised to include further data compiled within the NERP program that are relevant to support assessment and monitoring of CMRs and KEFs. For example, information on fishes within each reserve in the CMR network and KEFs will include the number of families, genera and endemic or listed species, and species of commercial interest. The continuing development of FishMap and the underlying datasets can provide tools to generate slices of data tailored for environmental managers: for example, endemics only, species represented in only one CMR, or species with a high proportion of their range within CMRs.

Tailored lists of fishes within each of the CMR reserves will highlight each area's unique values and contributions to conservation management. This can help to identify key species for demographic and genetic connectivity assessment (whole-of-organism approach) across CMRs, and circumstances in which off-reserve management would support conservation and sustainable-use objectives.

A wide range of information is available only to scientists or other specialists. Making data publicly and freely available through FishMap and the ALA is an example of the Hub's provision of broader access to scientific data: through interpretation and synthesis, and more accessible methods of data delivery.



ABOVE: **Examples of tailored maps and lists generated by FishMap, in this case for the Zeehan CMR.**

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Exploring the origins of Australian marine diversity

An evolutionary understanding of Australia's marine fauna can help to explain modern biogeographic patterns and assess the vulnerability-risk of fish families to present and future change.

Historical climatic and geological processes, as the architects of evolutionary change, offer a means of predicting the environmental conditions that promote changes in distribution, extinction or persistence. Because of its geological, climatic and geographic history, the Indo Australian Archipelago (IAA) is an ideal arena for examining the origins, speciation, diversification and colonisation of species across ecological climatic gradients, particularly in coastal habitats.

This project used selected fish families from the IAA and southern Australia to examine large-scale geological events or climatic changes that occurred millions of years ago, (such as the collision of the continents, or rising sea levels) for their influence on species creation and distribution. The findings highlight the origins of Australia's endemic marine fauna and the role of the continent as a biodiversity reservoir, from geological periods to the present day.

Approach

Specimens from the CSIRO Australian National Fish Collection were tissue-sampled for DNA extraction and sequencing to evaluate the genetic distances among species. Species evolution was placed into a timescale by calibrating the phylogenies with fossil records and a molecular clock to identify peaks of speciation or extinction. (The molecular clock hypothesis asserts that molecular sequences evolve at a relatively constant rate, so genetic differences between species can be related to the time since they last shared a common ancestor.) The resulting calibrated phylogeny is a reconstruction of the evolutionary history of each taxonomic group. Additional evidence, such as species distributions and habitat associations, were used to identify functional shifts.

Key findings

Australia and the mega diversity of the Indo-west Pacific

The maskrays, genus *Neotrygon* (Dasyatidae), originated following the collision of the Australian and Eurasian plates, with the ancestral, narrow-ranging endemic species appearing Austral in origin. Evidence from the *Neotrygon kuhlii* species complex, the most derived and dispersed group of the genus, suggests that mid-Miocene (15.7 million years ago) and Plio-Pleistocene falls in sea level (2–5 million years ago) may have accelerated species formation. Genetically distinct lineages survived in isolated refugia following the geographic fragmentation of a once large, continuous population into distinct genetic variants of different colours.

The tuskfishes, genus *Choerodon* (Labridae), diverged from their ancestral group, the Odacines, when extensive shallow water habitats formed at the onset of the Miocene (20 million years ago). Today, the widespread species in the group occupy a broad range of habitat types, with peripheral endemics in specialised reef or non-reef habitats.

Platycephalid flathead subfamilies Onigociinae and Platycephalinae diverged in the Eocene (35 million years ago) into mainly tropical and temperate species. Onigociins appear to have remained in the tropics and diversified since the early Miocene, while Platycephalins remained in temperate regions with only a few derived taxa reaching the tropics, possibly reaching the tropical Indo West Pacific from the Australian continent via tectonic rafting and shallow-water environments. Centrifugal speciation appears to have shaped diversity in both subfamilies across tropical regions.

Australia's iconic endemisms: a persistent source of diversity

Southern Australian endemic fish in the family Labridae (genus *Notolabrus*) were estimated to have evolved six million years ago. Monacanthids (leatherjackets) diverged as early as 16 million years ago, possibly in parallel with Australian labrid taxa. On the other hand, the stingarees, genera *Urolophus* and *Trygonoptera* (family Urolophidae), began speciation in the late Oligocene (27 million years ago). Modern members of these groups, such as *Urolophus bucculentus* and *U. flavomosaicus* appeared as recently as two million years ago. Patterns of sympatric diversification (along latitudinal gradients) and parapatric speciation, (gradual speciation from populations with overlapping zones of contact), assisted by depth preferences, were common, suggesting local speciation supported by sea level fluctuations and habitat preference.

New knowledge

Glaciation cycles of the Pleistocene had important biotic consequences in temperate and tropical waters, causing range shifts, extinctions and the formation of unique endemic species. Sea-level fluctuations in the past two million years, however, have not significantly accelerated the evolution of groups such as the temperate wrasses and leatherjackets, and the stingarees. On the contrary, since

LEFT: **A fossil of an extinct ray. The maskrays originated after the collision of the Australian and Eurasian plates and their speciation may have been accelarated by falls in sea level millions of years ago.** Image: John Adamek

diversification was static for the past two to three million years, it appears that extreme climatic events over geological time scales were necessary to achieve radical modifications in the distribution and composition of Australia's unique fauna.

Under the present-day climatic scenario, range shifts have been detected for some Australian marine species, especially with the southwards penetration of boundary currents. This could represent the beginning of rapid and drastic shifts in Australia's marine biodiversity, however accurate estimates of the severity of climatic alterations necessary for new species to develop, or for existing species to vanish, cannot be realistically determined.

The genealogical history in each of the analysed fish groups was influenced by multiple geological and climatic episodes. Each episode has left a distinct signature in the groups' ecological function, morphology and genome. The patterns observed point to the integrative importance of environmental affinities, ecological conditions and biotic interactions in shaping modern biogeographic patterns.

Synchronic speciation and the comparable biogeographic patterns in Australia's wrasses, leatherjackets and stingarees demonstrate the evolutionary and tectonic stability of the Australian southern marine platform over geological times and the importance of Australia's unique fish endemisms to the global marine diversity.

Outputs and outcomes

This project mapped the origins of selected Australian marine fauna, in particular its endemic species, providing knowledge that may help to guide realistic expectations for long-term sustainable management of Australia's marine natural resources. The Australian continent emerged as a reservoir of biodiversity for the indo-Pacific in geological periods and as a Noah's Ark' for biodiversity in modern days.

A conceptual framework and practical toolkit (molecular markers, genetic analysis protocols, biogeographic inference and modelling) has been created that is transferable to other marine groups.

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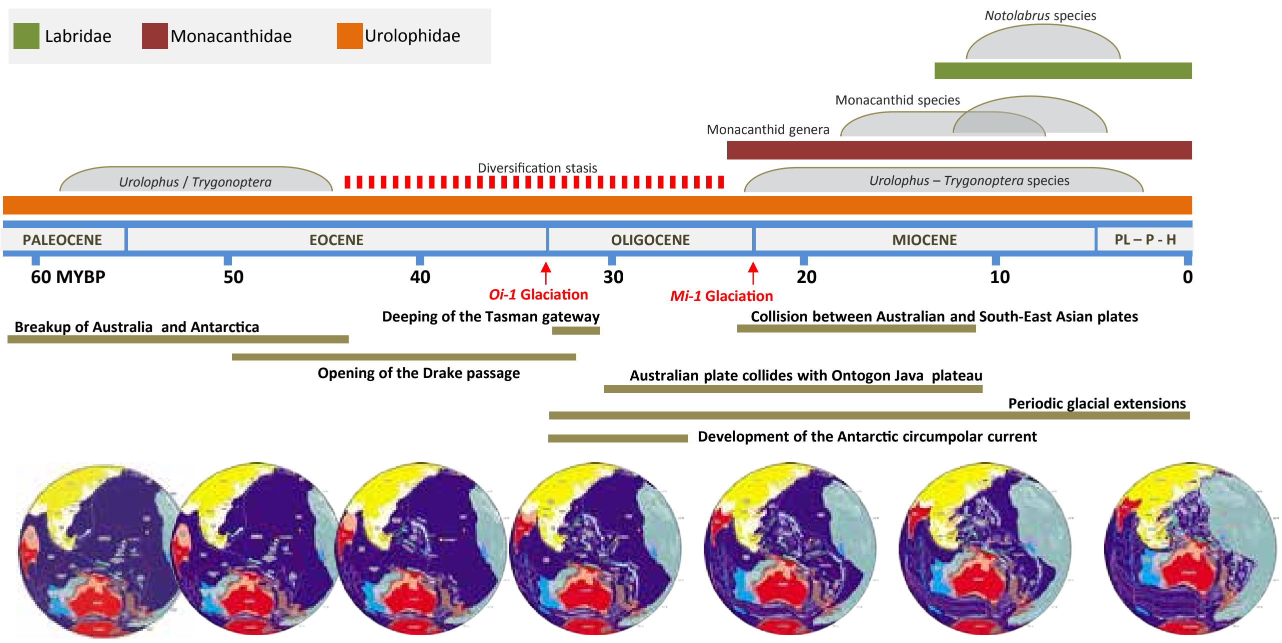
MAJOR GEOLOGICAL EVENTS AND THE TIMING OF DIVERSIFICATION WITHIN THE LABRIDAE, MONACANTHIDAE AND UROLOPHIDAE



ABOVE: **Selected fish families from the Indo Australian Archipelago were used to examine large-scale geological events or climatic changes that occurred millions of years ago for their influence on species creation and distribution.** Image: Nikos Andreakis (plate tectonic evolution of the past 60 million years from Robert Hall, 2002).

First maps of biodiversity across Australia's seafloor

Few national maps of marine biodiversity exist for Australia. Marine planning, and assessments of potential developments and conservation actions therefore have been based on a limited biological dataset.

This project accumulated new and comprehensive biological datasets for the Australian Exclusive Economic Zone (EEZ) including Antarctica, from depths of 0–2000 m. The datasets provided the basis for mapping seafloor fauna and species richness and turnover across the EEZ and neighbouring waters, and determining the best way to interpolate species distributions from existing records. It also examined the role of environment and history in forming biological communities, mapping evolutionary diversity, and identifying areas with clusters of phylogenetically distinct species.

The mapping contributes an improved knowledge and understanding of offshore seabed communities and can be used to identify areas of biological and genetic diversity that may require special consideration during planning decisions. It also supports future updates to the marine bioregionalisation for Australia.

Approach

Australian and overseas museum records, international databases, and taxonomic literature were collated into a comprehensive distributional dataset for two groups of benthic invertebrates: brittlestars and squat lobsters. Distributional datasets were analysed to map species richness and species turnover around Australia, taking into account the variation in sampling density and collection techniques between different regions. A genetic dataset was developed at the same time for these groups to ensure that conservation activities can prioritise taxa in divergent evolutionary lineages. A synthesis of the distributional and phylogenetic datasets will be mapped as a means of incorporating phylogenetic diversity in conservation planning.

Key findings

Depth (or rather correlated factors such as pressure and temperature) is the first order environmental predictor for species turnover/community composition on the seafloor. Fortunately, this means that fine-scale bathymetry data can be used as a (partial) surrogate of community composition.

Communities on the continental shelf and slope have evolved independently. These two biotas should be considered as inhabiting separate biomes, although they can overlap at outer shelf/upper slope depths (100–400 m). Preliminary data suggest that species on the abyssal plain have relatively recently evolved from those on the continental slope.

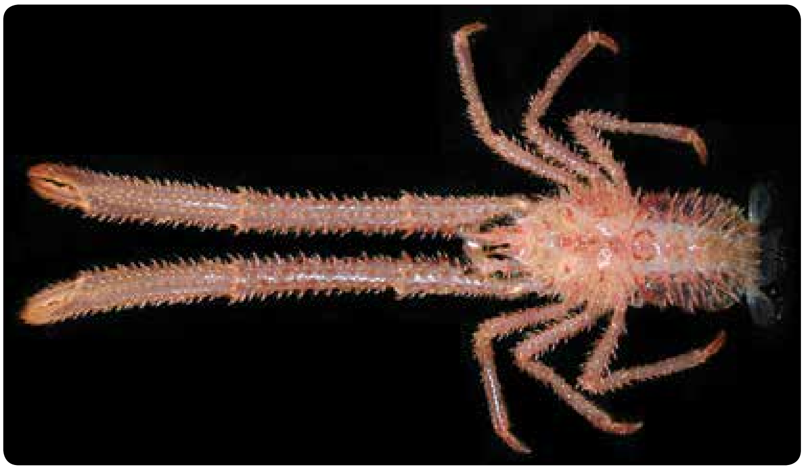
Seafloor communities within each depth biome are structured into latitudinal bands (tropical, temperate, polar). Within each of these bands there are variations in community composition by longitude and habitat. In shallow water, the south-western fauna differs by up to 50% from the south-eastern fauna.

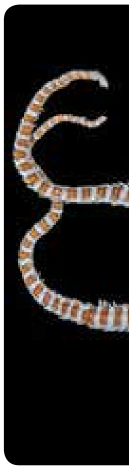
On the shelf and upper slope, species richness peaks at tropical/subtropical latitudes for both taxonomic groups, declining at temperate latitudes, and substantially declining at polar latitudes. The pattern is different on the middle and lower slopes and the abyss, where species richness peaks at temperate latitudes.

Species at bathyal depths (200–2000 m) can occur across extensive longitudinal ranges. For example, the seamount fauna of Tasmania is closely related to seamount faunas around southern New Zealand, and species on the southern Australian continental slope

BELOW LEFT: **This shallow water crab species (*Liomera edwardsi*) was collected in the Oceanic Shoals CMR off northern Australia, and is widely distributed across the Indo-West pacific. It may represent a cryptic species complex.**

BELOW: ***Uroptychus spinirostris* is an endemic species of squat lobster that occurs across northern Australia at about 400 m depth.**
Images: Anna McCallum, Museum Victoria





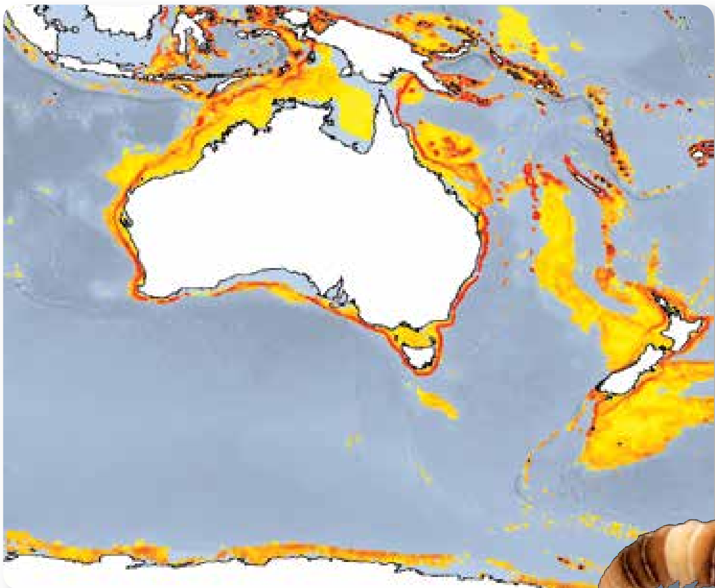
are also found at similar depths around New Zealand. The hard substratum fauna on the Macquarie Ridge is more related to the seamount faunas of south-eastern Australia and New Zealand than to seamounts adjacent to Antarctica.

'Species' with extensive bathymetric ranges are often composed of suites of cryptic species, each distributed into their own depth band. The magnitude of bathyal diversity has almost certainly been considerably underestimated.

New knowledge and opportunities

Datasets collated in this project can be used to predict seafloor community composition in most unsurveyed areas of the Australian EEZ. Exceptions include the Cocos Keeling and Christmas Island territories and the entire EEZ at lower bathyal to abyssal depths (3000–6000 m). They can also contribute to the future refinement of the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) classification scheme, a spatial framework that supports bioregional planning.

MODELLED SPECIES TURNOVER



Outputs and outcomes

Maps of seafloor fauna and species richness and turnover have been developed for the Australian EEZ and neighbouring waters, providing an improved knowledge base for identifying, assessing and managing biodiversity in Commonwealth waters. A deeper understanding of the origins of selected Australian marine fauna can help to explain modern biogeographic patterns and assess the potential impacts of future change (see story on page 14).

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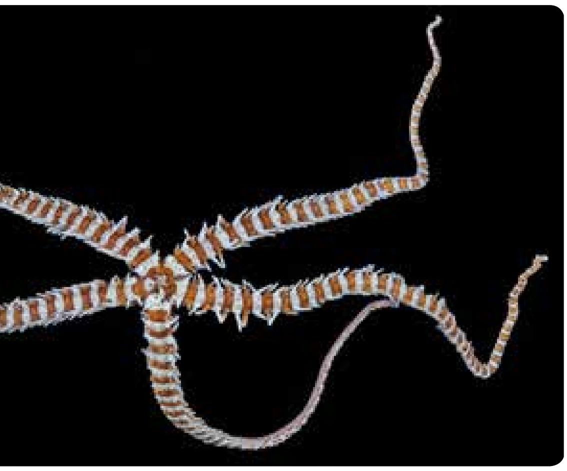
LEFT: **Modelled species turnover across the EEZ and Antarctic Territories. The darker colours indicate areas of most rapid species change.** Image: Skipton Woolley, Museum Victoria.

BELOW LEFT: **This species of brittle-star (*Astrogymnotes hasmishi*) lives upside down with its back to the host corals.**

BELOW: ***Sigsbeia oloughlini*, a new species described from the continental shelf off Esperance, Western Australia. Australia's shelf and slope fauna are not well known.** Images: Caroline Harding, Museum Victoria



Collating existing pressure data for the Commonwealth marine area

Understanding the pressures on the marine environment and their change over time is an important part of developing and prioritising management actions.

In the past, however, pressure data have not been collated, nor provided in formats that made them easy to compare. In addition, commercially sensitive data have often not been available for general display. This project mapped environmental pressures in Commonwealth waters (such as fishing, shipping, seismic surveys and oil and gas infrastructure) on a national scale and identified the associated risks and impacts in relation to marine biodiversity. The resulting capacity to assess the impacts of human activities on the marine environment will help the Department of the Environment to assess cumulative and relative impact and risk, and support the implementation of marine bioregional plans.

Approach

Existing data and information on key threats were sourced from the Commonwealth Environment Research Fund Marine Biodiversity Hub (the forerunner of the NERP Hub), national bioregional planning, CSIRO marine indicator and threat mapping projects, the Integrated Marine Observing System and the Australian Fisheries Management Authority. The data were analysed or aggregated to improve interpretation. For example sea-surface-temperature data were analysed and presented as long-term change, and commercial fisheries data were aggregated to obscure individually-confidential data points.

The distribution of pressures was mapped, and options were explored for combining qualitative and quantitative analyses of impact. Approaches and statistical tools were developed to investigate interactions between biodiversity assets and pressures and between multiple pressures as a stage in the development of cumulative impact indices.

New knowledge and opportunities

A simple data viewer was developed and deployed on the NERP Marine Biodiversity Hub website to provide simple access for Departmental staff to all the outputs of the Hub, including the pressure maps.

Pressure maps were aggregated and displayed in five-year bins to match the State of the Environment reporting interval and to allow straightforward assessment of whether the footprint for individual pressures had increased or decreased in the past few decades.

Outputs and outcomes

One hundred and twenty six different layers of pressure data, with associated metadata records, have been collated for the Commonwealth Marine Reserve network. They include summaries of the current status of oil and gas extraction and infrastructure, seismic surveys, shipping movements, aquaculture leases, pollution events, trends and variability in changes on ocean temperature. The data have been archived on the Australian Ocean Data Network to ensure their long-term availability to Departmental databases.

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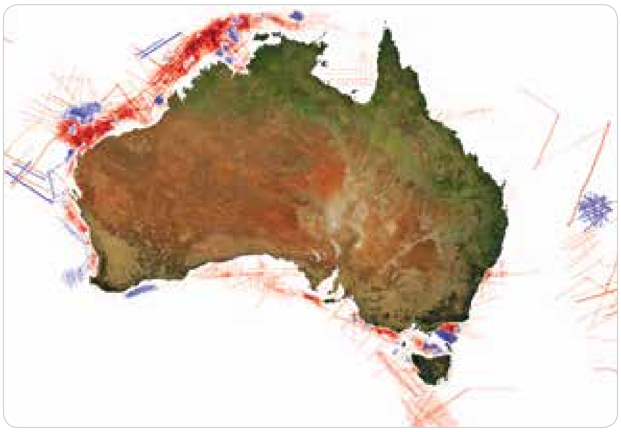
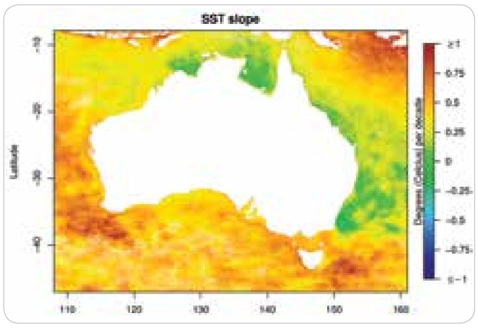
CHANGE IN SEISMIC SURVEYS



SHIPPING ACTIVITY AND SEISMIC SURVEYS

SEA-SURFACE TEMPERATURE CHANGE



ABOVE: **Examples of collated pressure data for Commonwealth waters (from top).** Images: CSIRO

Change in seismic surveys (red: pre-1996; blue: 2006–2010). The collated data show the extensive surveying done before 1996, and the reduced seismic footprint in later years.

All shipping activity for shipping greater than 200 tonnes around Australia: 2006–2010 (green to red, low to high activity) and the sum of all the seismic surveys for the same period (blue).

Estimated sea-surface temperature average long-term linear change, (°C per decade). Areas of orange and red indicate warming during 1993–2013 (south-western Australian and eastern Tasmania); areas of green and blue indicate cooling (eastern Australia and northern Australia).

Assessing relative and cumulative impact on the marine environment

Pressures on the marine environment are steadily increasing with new uses including renewable energy and new pressures including warming and more acidic seas.

Some of these pressures will threaten conservation values and the impacts can be cumulative. Predicting the location and magnitude of these impacts can be challeging. A scientifically robust and pragmatic approach is needed that can estimate the overall cumulative impact of pressures, as well as detect how different pressures contribute to the overall impact (their relative impact). This will provide managers and regulators with information to underpin policy, regulatory or management responses. In this project, fisheries and biodiversity conservation scientists worked with the Department of the Environment to examine and advise on the development of cost-effective approaches to understanding and estimating cumulative impact on marine biodiversity assets in South-east Australia.

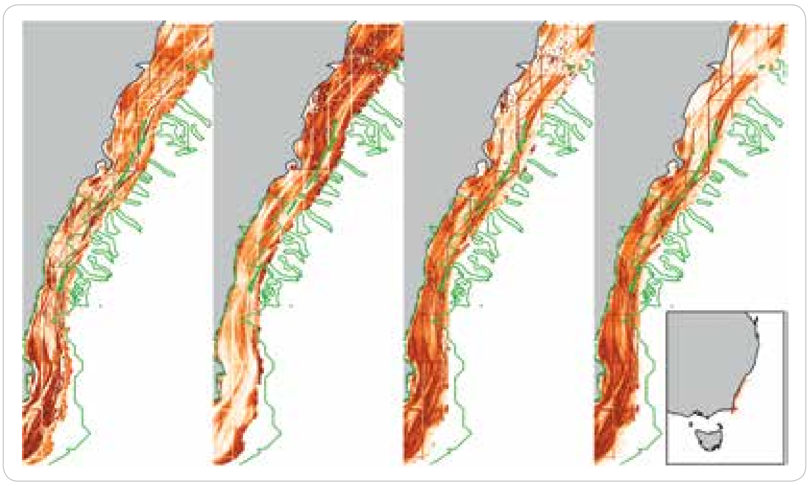
Approach

The project team identified three broad approaches that have been applied to understand and estimate cumulative impact on biodiversity assets on the continental shelf in South-eastern Australia: expert elicitation, qualitative mathematical models and quantitative mathematical models. Expert elicitation is a relatively simple, low cost approach used by the Department in marine bioregional planning to assess the potential for cumulative impact on conservation values, including biodiverse submarine canyons and shelf rocky reefs (identified as Key Ecological Features).

Qualitative mathematical models were used by CSIRO to identify ecological indicators sensitive to cumulative impact on submarine canyons and shelf reefs. They identified important ecosystem components, and how these are linked and affected by pressures. High-resolution statistical models were used to retrospectively predict the cumulative impacts of 20 years of trawling on demersal fish communities on the continental shelf of South-eastern Australia.

An examination of these three approaches highlighted their relative strengths and weaknesses in terms of simplicity, cost, data requirements and uncertainty. It also demonstrated how each approach can complement each other when arranged in hierarchical manner, from simple, rapid and low cost approaches to more complex and costly approaches. This hierarchical approach to estimating cumulative impact supports timely decision making based on available information, enabling additional scientific understanding to be incorporated when available, and identifying potential research investments.

20-YEAR CUMULATIVE EFFECT OF TRAWL FISHERIES



ABOVE: **The 20-year cumulative effect of trawl fisheries on four groups of demersal fish species. Darker areas indicate higher cumulative impact. KEFs identified in the south east are overlaid in green.**

New knowledge and opportunities

The application of many tools and approaches for assessing cumulative impact is limited by the availability of knowledge, data and resources, and uncertainty. It might be desirable to have a single tool that could always be used to meaningfully assess cumulative impact and attribute relative impact, but the circumstances in which this is possible are limited.

The hierarchical approach developed here provides a framework for identifying the minimum set of tools required to understand the potential for cumulative impact and progress to more sophisticated approaches to assess cumulative and relative impact where this is required and possible. For example, the project identified three different processes to produce a three-level hierarchical approach to assess the cumulative impact of trawling.

Outputs and outcomes

Collaboration with the Department and fisheries scientists has enabled the Hub's researchers to propose a hierarchical approach to understanding and estimating cumulative impacts and relative impacts that is scientifically robust, practical and incorporates tools already used to inform decision making processes.

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Biodiversity offsets in the marine environment

ABOVE: **Choice modelling elicited community preferences for offsetting in relation to seagrass habitat in WA waters.** Image: Curtin University

On land, biodiversity offsets are an established instrument for reconciling economic development with biodiversity conservation. In the marine environment, however, the potential is still being explored.

This research examined issues associated with the design and implementation of marine biodiversity offsets. First, the performance of offset strategies (comprising a management approach and offset objective) when cumulative impacts are present, and second, community preferences for aspects of offset design (such as location/distance from the impacted site and direct or indirect offsets). The effect of offsetting on developers' social licence to operate was also explored. These issues are pertinent to agencies responsible for conserving marine biodiversity and regulating activity, particularly given the complexity of the marine environment, uncertainty around impacts, and increasing pressures and demands for use. Such issues have the potential to generate community concern about resource allocation.

Approach

Different approaches and methods were used to address each issue. A simple socio-ecological model was used to simulate the effect of annual development projects occurring over five consecutive years on habitat and resource recovery, human utility and offset costs under four different offsetting strategies. Choice modelling was used to elicit community preferences for biodiversity offsets for migratory shorebirds (Queensland and Western Australia) and seagrass (Western Australia), and a four-dimensional framework was used to evaluate the effect of offsetting on the Western Australian oil and gas industry social licence to operate. Data were collected through online public surveys.

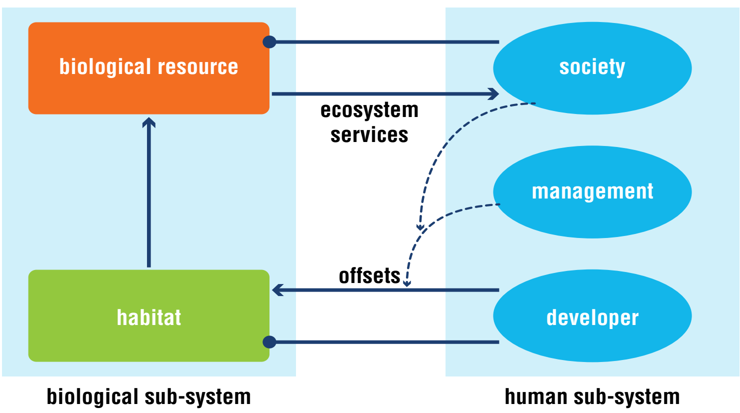
Key findings

Socio-ecological modelling highlighted the importance of adopting an offsetting approach that either took a strategic assessment approach to development approvals, or explicitly accounted for cumulative impacts in project-by-project assessments. The link between alternative offsetting approaches and the distribution of offset costs across developers was also shown. A novel aspect of the research was that it accounted for the possibility that societies may allow a threshold level of damage to occur before requiring offsets, (depending on their perception of habitat status).

Respondents had strong preferences for offsets close to the original project, and a strong aversion to shifting the offset overseas, even if the costs of implementing the offset were much lower there. Distant offsets were only acceptable if the pay-off (additional shorebirds protected) was sufficiently high. Also, respondents were willing to accept protection of a smaller number of endangered shorebirds as compensation for losing numbers of common species. Indirect offsets (such as research and education) were considered acceptable if more birds were protected as a result.

Offsetting does not have a negative effect on a developer's social licence to operate, (conditional upon the offsets achieving the stated ecological outcomes).

MARINE SYSTEM OFFSET MODEL



ABOVE: **The marine system offset model links biological and human systems. The arrows denote positive effects, and the lines ending in dots denote negative ones. The habitat element supports a biological resource exploited by society in a predator-prey relationship. Habitat is damaged by development, but may be remediated by offsets. The relative strength of this remediation is determined by management, which in turn is influenced by a social process that allows a threshold level of ecosystem service loss before offsets are required (dashed blue lines).**

Outputs and outcomes

This research has begun building the knowledge required for the effective design and implementation of offsets in the marine environment. The socio-ecological marine system offset model is being enhanced to address additional questions, such as the uncertainty assumptions under which offsets portfolios are designed. Research on public attitudes to offsetting, including its effects on social licence to operate, and on preferences for offset attributes, can help policy makers, managers and developers identify socially acceptable approaches. It can also contribute to communication and education strategies that align public preferences for offsets with environmental effectiveness.

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Potential for incentive-based management for marine conservation

Incentive-based management is increasingly being used to manage industries that interact with the environment.

Fundamental to the concept is the notion that environmental damage could be reduced if the costs were borne by the individual or industry responsible. Appropriate incentives – either an explicit price (such as a tax) or a market-based opportunity (such as a tradeable quota) – can provide efficient ways to reduce or limit environmental damage.

Incentive-based marine management has largely been limited to fisheries quotas. These have been applied to limit turtle and mammal bycatch in the United States, Canada and New Zealand with mixed success, partially due to quota type and low-frequency species interactions. Some tourism-based industries pay a bond to operate in environmentally sensitive areas (such as dive and day-trip boats in the Great Barrier Reef).

This research explored the potential for incentive-based management to limit environmental damage in two areas: the dumping of dredge spoils at sea, and interactions between fisheries and high-conservation-value species and habitats.

ABOVE: **Some tourism-based industries, such as dive and day boat trips in the Great Barrier Reef, pay a bond to operate in environmentally sensitive areas.** Image: Matt Curnock

Approach and methods

The research was largely review-based, with a qualitative assessment of how a range of existing Commonwealth and State incentive-based measures may work (in the dredging and fishing industry), and an exploration of how different instruments might change these incentives. International experiences in marine environmental management were also reviewed. In the case of fisheries impacts to habitats and species, most reviewed studies were largely theoretical or model based, as relatively few countries have adopted incentive based management approaches for non-target species or habitats.

Key findings

In the case of dredging, Commonwealth and State legislation is largely based on a permit system, the granting of which depends on the expected environmental impact. Once approved, it generally provides no incentives to minimise the quantity of spoils dumped at sea. In some cases, limits on the amount of spoils are set as part of the approval process. Based on other studies, a combination of a bond and levy based system to provide incentives to minimise the impact (in terms of volume and where dumped) was considered an optimal outcome. An offset system should form part of the package.

RELATIONSHIP BETWEEN THE FREQUENCY OF IMPACT AND THE MANAGEMENT APPROACH

	management measure	
frequency of impact	**bycatch**	**habitats**
infrequent	charge/penalty (low divisibility for quota)	assurance bonds/insurance
frequent	quota (better divisibility/too many notices to issue penalties)	individual habitat quota

ABOVE: **Individual quotas can offer benefits for managing high frequency impacts on bycatch species and habitats.**

In the case of fisheries environmental impacts, the optimal incentive-based management measure depended on the frequency of impact and the impacted matter. For infrequent bycatch species (such as seabirds), a levy based system was most likely to be effective, but this approach has had little international application internationally due to a reluctance to use tax-related management measures. In contrast, for high-frequency bycatch species, individual quotas offered benefits. For habitats, assurance bonds and/or insurance based systems were most appropriate when impacts were relatively infrequent. Model based analyses suggest individual habitat quotas were likely to be most suitable when impacts were likely to be frequent.

Outputs and outcomes

This research has clarified the potential of incentive-based measures as tools for policy makers. It has provided guidance on incentives faced by commercial operators with respect to unpriced outputs of the production process, and the measures available to manage these, as well as mixes of incentives appropriate for specific circumstances.

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Landscape approaches for managing sharks and rays

Many species of sharks and rays are slow-growing, long-lived, and have low rates of reproduction.

These characteristics make them vulnerable to the impacts of human activities, and populations can take decades to recover once they have declined. Nine species of sharks and rays are protected in Australia under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*), and the population status of more than 10 further species offers cause for concern.

Marine spatial planning for sharks and rays is challenging because many species traverse inshore areas managed by different states, offshore waters managed by the Commonwealth, and spatial closures covering both. Cost-effective, integrated spatial management requires identifying areas in which several species co-occur. Importantly, proposed management measures for individual species need to be jointly evaluated as they could help one species while harming another.

Approach

This project improved species mapping, identified areas shared between species, and measured the overlap with existing marine spatial planning areas, with a focus on temperate waters off south-eastern Australia.

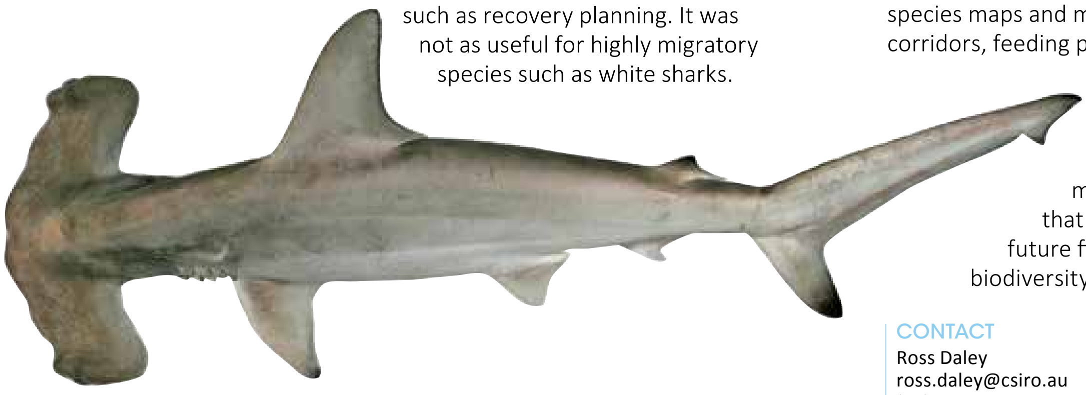
Species maps from the Atlas of Living Australia were improved using updated seafloor bathymetry overlaid with fishery catch data (where available). The maps were refined in workshops attended by 23 specialists who also helped to group species according to movement patterns.

Shared areas were mapped by overlaying species maps in each group. This simple, biogeographic approach avoids some of the (time and spatial) scale issues with alternative approaches. For example, while geomorphology has been used as a proxy for critical habitat, shark breeding and foraging ranges occur at finer scales than the available mapping.

Key findings

Common corridors, feeding patches and breeding patches were identified around temperate Australia. Several feeding patches were within CMRs, and most breeding areas were in state waters. Corridors stretched for hundreds of kilometres and these are only partially protected by marine spatial planning.

The landscape approach was found to have higher utility for benthic sharks, skates and rays, which often are overlooked in conservation activities such as recovery planning. It was not as useful for highly migratory species such as white sharks.



The Scalloped Hammerhead Shark, *Sphyrna lewini*. Image: CSIRO

TOP: **Eagle Ray distribution in south-eastern Australia. Green: adult core range; orange: adult minor range.** Image: Ross Daley

ABOVE: **The Eagle Ray, *Myliobatus tenuicaudatus*.** Image: CSIRO

New knowledge and opportunities

Many species of sharks and rays share similar breeding grounds, feeding grounds and corridors. It is possible to gain better management outcomes by integrating existing areas identified for marine spatial planning with areas used by many species. This would improve the general conservation of sharks and rays while limiting reductions in resource access. Marine spatial planning alone is not a full solution, however, and corridors will be difficult to manage.

Outputs and outcomes

This project generated improved species maps and maps of common corridors, feeding patches and breeding patches, identifying areas used by many species that will assist future fisheries and biodiversity management.

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Identifying important areas for pelagic fish

Seabed features such as canyons, seamounts, banks and shoals provide aggregation points for ocean (pelagic) predators such as tunas and mackerels.

Learning more about this relationship can offer insight into the distribution patterns of these wide-ranging species, and may present opportunities for monitoring programs and the assessment of management initiatives such as Commonwealth Marine Reserves (CMRs). This research sought to identify relationships between pelagic predators and seabed geomorphology to support the management and monitoring of conservation values inside and outside the CMR network.

Approach

A literature review assessed knowledge of predator dynamics in relation to seabed geomorphology. Of particular interest were relationships between predator species and seabed features and methods used to quantify these relationships, as well as the use of landscape metrics (standard measures) by ecologists.

Model simulations determined which metrics best captured seabed complexity and showed promise for monitoring the responses of predators to seabed features. The distribution of oceanic predators such as tunas and mackerels was modelled in relation to seabed geomorphology such as canyons to find continental-scale patterns in marine biodiversity.

Key findings

The study of long-term commercial catch data off Western Australia found geomorphology to be a key predictor of the distributions of tunas, marlins and mackerels. Data for other pelagic predators including marine mammals and sharks were less available (no fishery data, or poor bycatch data). Many areas of predicted high pelagic fish diversity fell outside the CMR network, particularly those in the Gascoyne Coast, South and West Coast bioregions. Where predicted areas did fall within in CMRs, they often fell within multiple use zones, indicating the importance of how these multiple use zones are managed.

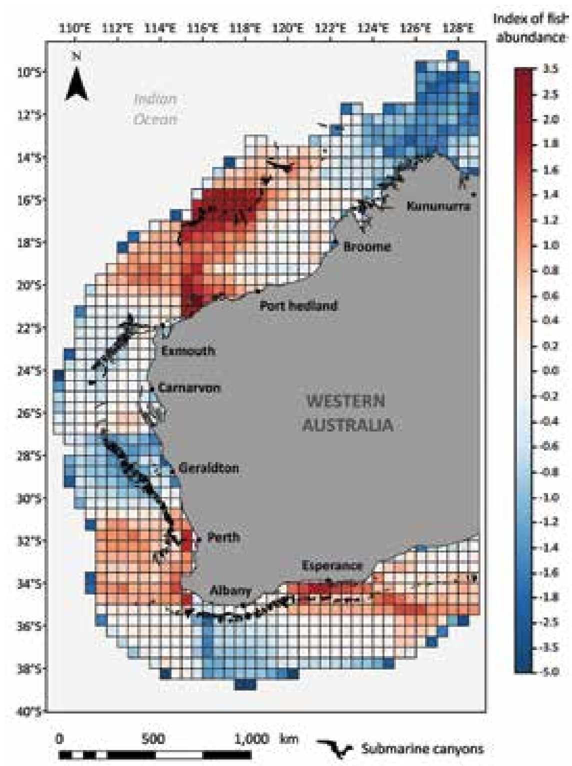
Historical, global fisheries datasets – such as those produced by the Sea Around Us Project – are among the most extensive information sources available for many marine organisms. They can be a useful avenue for identifying important biological processes, and a continental-scale view of predatory dynamics, in the data-deficient pelagic ocean. With careful treatment, they can act as a foundation for determining conservation priorities on scales much broader than local surveys could capture. Identified hotspots can then be refined and further studied on local scales.

New knowledge and opportunities

A new understanding of relationships between geomorphology and pelagic fish assemblages can support the effective design, internal zoning, management and monitoring of CMRs in the open ocean.

Fisheries-derived data relating to large fish such as tunas provide a valuable tool to support marine conservation and ecology and further analyses of these data across Australia's Exclusive Economic Zone (EEZ) would help to identify opportunities for conserving pelagic megafauna inside and outside CMRs. (Similarities between the predicted hotspots of tunas and those of other large predators such as blue whales and tiger sharks have been observed in other studies, suggesting tunas can be used as proxies for pelagic diversity.)

PREDICTIONS OF PELAGIC FISH ABUNDANCE



ABOVE: **Modelled predictions of pelagic fish abundance, showing three main regional-scale hotspots (red areas): one in the north, one in the south-west and one along the southern coast. Submarine canyons are shown in black.** Image: Phil Bouchet, UWA

Outputs and outcomes

This project has contributed an increased understanding of the relationship between geomorphology and pelagic fish that can be applied to CMR monitoring and assessment, environmental impact assessments for offshore oil and gas, and fisheries management. A pelagic fish and sharks dataset linked to an environmental dataset including static (geomorphometric) and dynamic data is now available for the EEZ adjacent to Western Australia.

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Predicting benthic impacts and recovery to support biodiversity management in the South-east Marine Region

Many animals and plants live attached to the seabed where they form benthic habitats used by a diversity of other species.

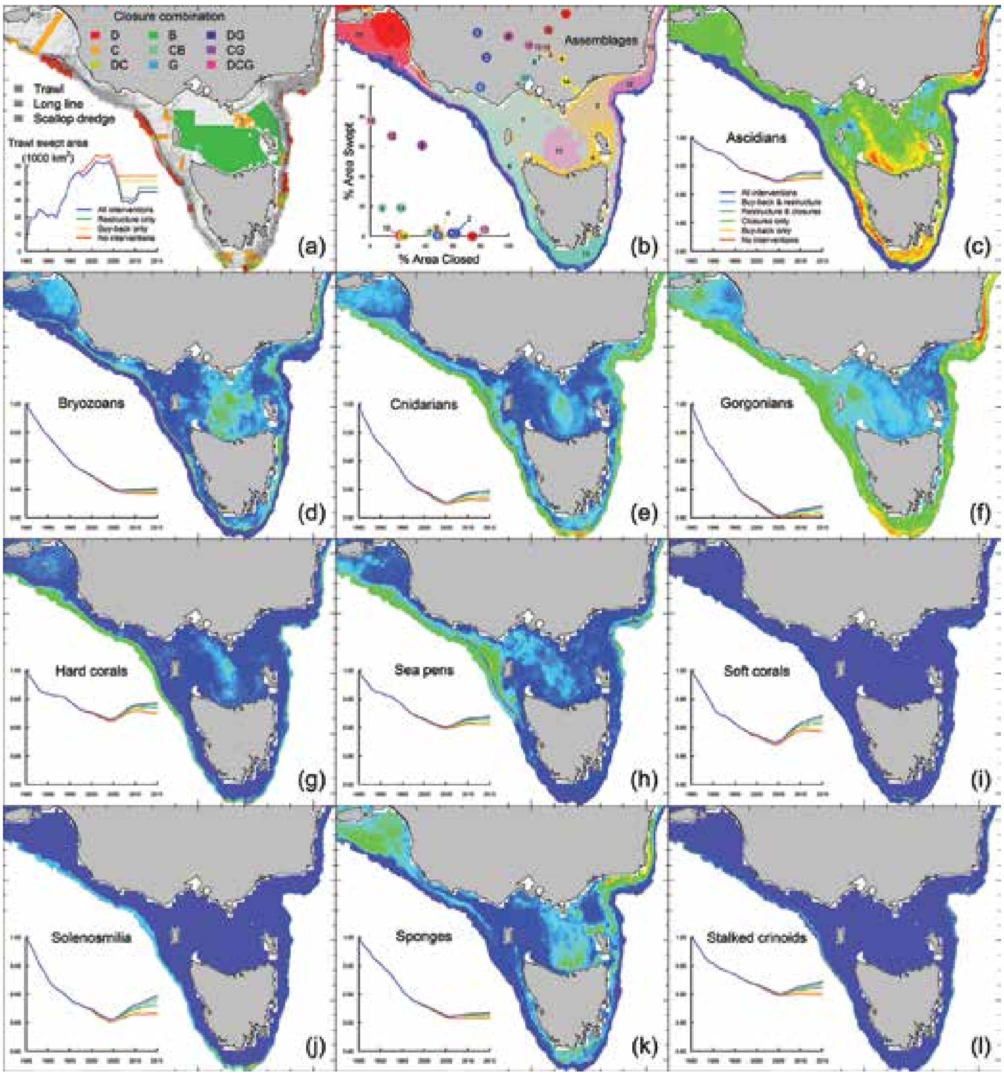
These habitats can be affected by human uses in the marine environment and a range of management measures have been implemented to reduce these impacts. This project sought a better understanding of the types of taxa that form benthic habitats: their distribution, sensitivities and management measures that provide protection from pressure. It produced the first regional-scale distribution maps for benthos in the South-East Marine Region (SEMR), and assessed the impacts of human uses (including cumulative effects) and the efficacy of existing management strategies for epibenthic fauna.

Approach

A trawl-simulation model developed for tropical regions was reconfigured to quantify and assess cumulative threats, risks to benthic biodiversity, and the effects of discrete management actions in the SEMR. The model incorporated predictions of biodiversity assemblages and habitat-forming benthos, in addition to their exposure to fishing and levels of protection (derived from existing data sources).

Survey data were collated for benthic species on the continental shelf and upper slope, as well as information on impact and recovery rates in relation to human uses. Biophysical modelling was used to characterise, predict and map patterns of biodiversity assemblages (spatially unique mixtures of all species, including mobile invertebrates and fishes), and the distributions and abundance of the major habitat-forming taxa such as sponges, coral, gorgonians and bryozoans.

CLOSURES, ASSEMBLAGES AND TAXA TYPES IN THE SOUTH-EAST MARINE REGION



RIGHT: **(a) Post-1985 footprints of the main bottom fisheries (cross-hatching) over four main 2013 trawl closure types: [D] Deep water closure, [C] CMRs, [B] Bass Strait closure and [G] Gulper shark closures. (Light grey shading: open areas.) The inset plot shows actual trawl effort time-series and alternative effort scenarios.**

(b) Bio-physical characterisation with 15 predicted species assemblages (environments in which biological composition is expected to be relatively similar, and between which composition is expected to vary). Their degree of similarity is indicated by the proximity and colour of the legend symbols. Assemblages may not be spatially continuous. The inset plot shows the inclusion of assemblages in closed areas, and exposure to trawling.

(c–l) Images and predicted distributions of 10 major taxa types of habitat forming benthos (relative density: blue=low through to red=high). Each inset plot shows predicted abundance time-series, relative to 1985, from simulation modelling of trawl effort on the taxa type distribution (from no management interventions to all interventions).

INCLUSION OF BENTHIC BIODIVERSITY IN CMRS AND FISHERY CLOSURES, AND EXPOSURE TO HUMAN USES

	SEMR shelf and slope: area affected	15 spatially unique assemblages: area affected	Overlap with habitat-forming benthos taxa types (by abundance)*
CMRs	~9% (excluded 1.1% of historical trawl effort)	0–41%	7–19%
Trawl closures	~39% (excluded 5.5% of historical trawl effort)	1–81%	33–60%
CMRs and closures	~44% (excluded 6.2% of historical trawl effort)	1–83%	40–63%
Exposure to trawl effort since 2007	~6% of seabed trawled (across ~23% of the region)	0–43% (3 most exposed assemblages trawled 2–3 times yearly on average)	1–9% (most-exposed taxa trawled ~2 times yearly on average; annual overall trawling impact ~1–8%)
Longlining (widespread, but lighter impact)	~0.03% of seabed long-lined (spread over ~17% of the region)	0–0.12%	0.01–0.03% (annual impact 0<0.01%)
Scallop dredging (Commonwealth only)	~0.01% dredged (spread over 0.38% of region)	0–0.05%	0–0.02% (annual impact 0–0.01%)
Oil and gas facilities and pipelines	~0.05% (spread over 0.52% of region)	0–0.20%	0–0.05%

** Survey data for habitat-forming benthos are sparse and patchy, thus prediction maps have high uncertainty.*

Fishing and other human activities that affect the SEMR seabed were mapped from collated data. For the fishing industry (particularly trawling) this included historical annual fishing effort by area, fishing operations and management actions (including effort reductions, closures to fishing and the Commonwealth marine reserves system). Information was also collected in relation to oil and gas infrastructure.

Key findings

The effects of fishing were modelled for 15 spatially unique species assemblages and 10 habitat-forming benthos taxa types that had been predicted and mapped from survey data*. Simulation of the bottom trawl fishery from ~1985, (when consistent logbook records were available), showed that all 10 benthos taxa types declined in abundance in trawled areas until the mid-2000s. At this time fishing effort reduced due to economic pressures and licence buy-backs, and large areas were closed to trawling. A complex picture emerged, with patterns and responses varying spatially according to the distribution of benthos taxa types, trawling distribution, and type of management action.

The lowest total regional abundance (status) of habitat-forming benthos taxa types across the SEMR was ~80–93% of pre-trawl status, after effort peaked during 2000–2005. Subsequently, all taxa were predicted to recover by varying extents (~1–3%) in the following decade. Had none of the management actions been implemented, benthos status was predicted to stabilise or recover slowly, and with all management actions in place, the rate and magnitude of recovery was greater. Reductions in trawl effort universally improved the status of habitat-forming benthos, with the larger 2006 licence buy-back leading to greater improvements than the 1997 buy-back.

In some cases, spatial management that excluded trawling, (particularly deepwater fishery closures), led to improved status of some benthos taxa types. Most fishery closures and CMRs had little detectable influence on status, though in some cases they worsened the status of some taxa in some locations. This was because displaced trawl effort moved to areas in which some taxa were more abundant.

New knowledge and opportunities

The new approaches can be used to evaluate existing and potential future management measures, and also be applied to assess the status of benthos in other marine regions. There are opportunities to reduce the uncertainties and data gaps in the map of benthos taxa types, by conducting new surveys of the distribution and abundance of habitat-forming benthos taxa.

Outputs and outcomes

An unprecedented level of data integration led to improved knowledge and understanding of benthic biodiversity distribution, protection, vulnerability and status. It enabled the first regional scale quantitative analysis of pressures and cumulative impacts, and the first quantitative evaluation of management strategies for benthic biodiversity conservation. This advanced capacity to evaluate existing and potential alternative biodiversity management options on and off reserves, as well as the relative impact of alternative pressures including marine industries, supports evidence-based decision making in these difficult-to-observe offshore environments.

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Collating existing survey data for Commonwealth marine waters

The Australian Government has identified 58 Commonwealth Marine Reserves (CMRs) and 54 Key Ecological Features (KEFs) in Australia's Commonwealth marine area. Collating existing data and information about these areas is critical to effective biodiversity management and protection.

Approach

An overarching catalogue equipped with powerful, standardised search tools was needed to integrate and enhance the value of disparate marine databases relevant to Australia's CMRs and KEFs. The catalogue developed in this project, the Australian Region MARine Data Aggregation (ARMARDA) facility, provides a single entry point to databases held by a suite of national research networks and agencies and has an unprecedented level of functionality.

ARMARDA is able to upload physical and biological observation data via websites from CSIRO, the Australian Institute of Marine Science, the Australian Ocean Data Network, Geoscience Australia, the Integrated Marine Observing System, the Institute for Marine and Antarctic Science and the Terrestrial Ecosystem Research Network (TERN). ARMARDA is not yet able to search all existing marine data from these providers, but there is strong potential to make more data from these sites visible.

In consultation with staff from the Department of the Environment and Environmental Resources Information Network, a protocol for updating and editing shape files (a file format used for storing geographic information data in GIS computer programs and databases) for KEFs is being established. Improved KEF boundaries will enhance the assessment of existing data sources for each KEF.

Outputs and outcomes

Data summaries are available for 50 regions associated with KEFs, and 173 zones in CMRs. The ARMARDA webpage enables the rapid spatial and temporal summary of existing data sources for all Australian KEFs and CMRs. Data rich and data poor areas can be identified.

ARMARDA aggregates data for irregular-shaped areas, includes the spatial and temporal resolution of the data, and caters for users who are new to an area of interest. This is a significant advance on the functionality of previous search tools for marine databases.

www.cmar.csiro.au/data/armarda

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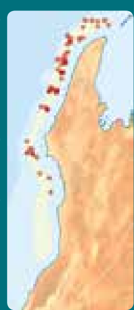
Inside the data catalogue

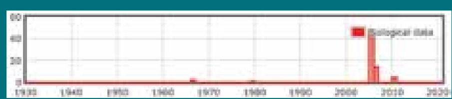
A preliminary analysis of the data catalogue shows that most observations in the past 50 years have targeted oceanographic variables, with some biological sampling of upwelling and eddy systems, canyons, deep and shelf seabeds. These data are unlikely to support baseline status assessment, although community composition data may serve as a reference point for contemporary changes associated with climate change. Most biological sampling has been at shelf reefs and areas of enhanced pelagic productivity. These data, augmented by satellite ocean colour observations, are likely to support baseline status assessment in some areas.

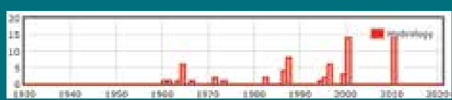
The maps and graphs are sample outputs from the data catalogue. At Ningaloo Commonwealth Marine Reserve, biological sampling records are primarily from baited remote underwater video stations in 2005, while hydrological sampling spans 50 years.

NINGALOO CMR


biological data map

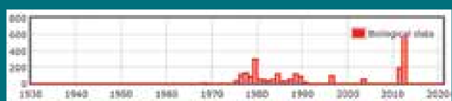

hydrological data map

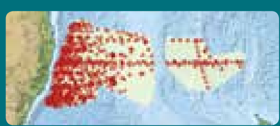

biological data graph

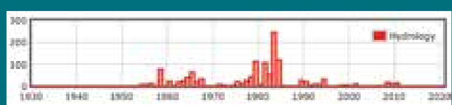

hydrological data graph

TASMAN FRONT AND EDDY FIELD KEF


biological data map


biological data graph


hydrological data map


hydrological data graph

Both datasets show a relatively patchy distribution. At the Tasman Front and Eddy Field KEF, sampling is also patchy, but with greater intensity dating back to the 1950s. Biological sampling has targeted pelagic fish and plankton communities.

Analysis of approaches for monitoring biodiversity in the Commonwealth marine area: Oceanic Shoals

Carbonate banks and terraces of the Van Diemen Rise and the Sahul Shelf, and pinnacles of the Bonaparte Basin (North and North-west marine regions) are Key Ecological Features (KEFs) represented in the Oceanic Shoals Commonwealth Marine Reserve (CMR).

These features, with their abrupt bathymetry presenting a range of substrates, aspects and depths, were considered potential biodiversity hotspots, and merited further investigation. This project explored and discovered new marine biodiversity information, with a ship-based expedition in the RV *Solander* to previously unsampled carbonate banks and pinnacles in the western part of the Oceanic Shoals CMR. The information is being integrated with existing data to better understand biodiversity distribution and sensitivity in this area of active offshore exploration and development.

Approach

The collaborative nature of this project capitalised on the unique expertise of the research partners. A 25-day voyage involving the Australian Institute of Marine Science, Geoscience Australia, the Museum and Art Gallery of the Northern Territory, and the University of Western Australia targeted three rectangular areas. Each rectangle covered approximately 200 km² of seabed and contained one or more banks or pinnacle features and contrasting non-KEF habitats. Multibeam sonar and other acoustic tools were used to create high-resolution seabed maps and benthic biological material was sampled with epibenthic sleds. The project also observed seabed habitats and fish communities with cameras including towed video (and associated stills cameras) and benthic and pelagic baited video stations.

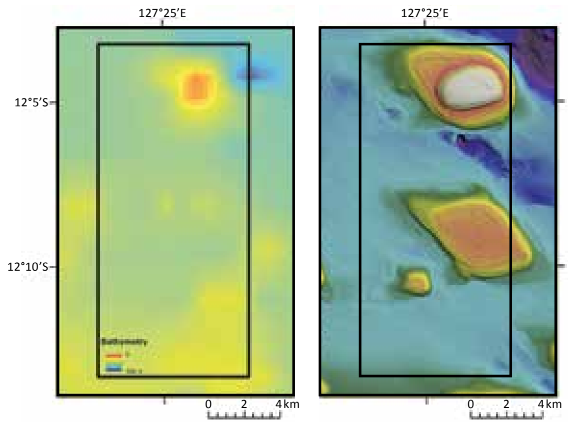
Key findings

The Western Oceanic Shoals CMR contains more banks and pinnacles than previously thought, with high resolution mapping in four survey areas revealing 41 banks and pinnacles covering an area of 152 km², an increase from 105 km² (~33%). This finding suggested that the number of banks and pinnacles is likely to be significantly greater throughout the CMR than previously had been indicated by available charter or the bathymetric data in the 250 m grid national bathymetric database.

In general, open, low-relief areas of continental shelf supported very low abundances of macrobenthos. The sampled biotas were dominated by sponges, with soft corals the next dominant group, and much lower numbers of other major taxa. Sponges and soft corals were mostly associated with the sides and plateau areas of banks and pinnacles. Benthic biodiversity and abundance on banks and pinnacles decreased with water depth and across the transition, from the hard substrate of banks to soft sediment plains.

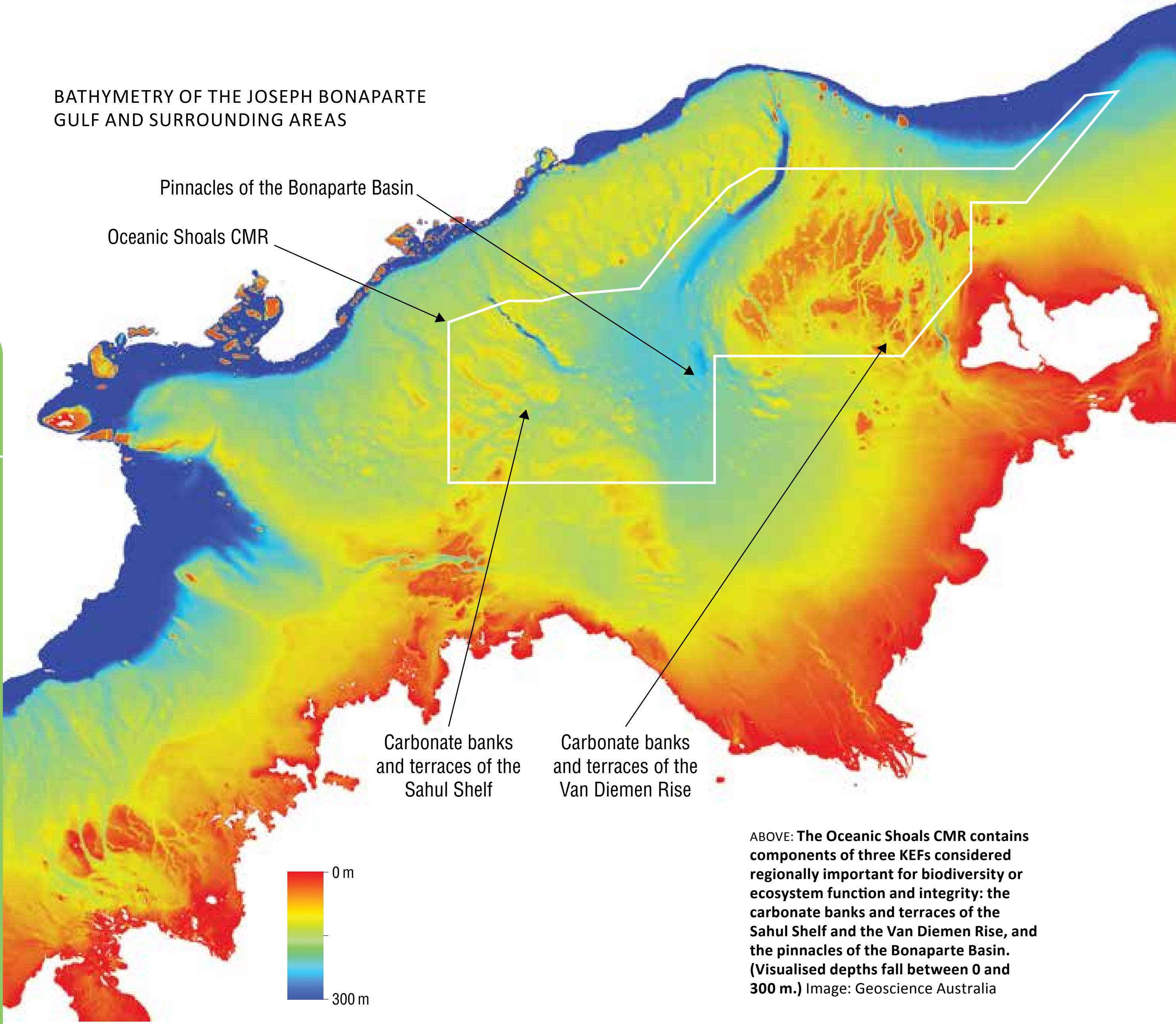
The high diversity of sponges, in particular on raised geomorphic features (banks, pinnacles, ridges, terraces) compared to subdued features (plains, valleys), adds to the

ABOVE AND RIGHT: **Benthic biological material was sampled with epibenthic sleds. Twenty-nine sponge species collected are new to science, with as many as 100 potential new species yet to be confirmed. Sediment-dwelling animals were highly diverse with 266 observed species, including newly discovered species of sea spider, squat lobster and worm.**



ABOVE: **A bathymetry map before the 2012 survey with a spatial resolution of 250 m (left) compared with the same area mapped by this project at a spatial resolution of 2 m. The high resolution sonar mapping revealed 41 banks and pinnacles covering an area of 152 km², an increase of 33% from 105 km² of previous surveys.**

The carbonate banks, terraces and pinnacles of the outer Sahul Shelf were built by repeated episodes of reef growth during high sea level (interglacial) phases of the past two million years. These features were then shaped by erosion and weathering during the low sea level of a following ice age. Today, tidal currents shape and score the seabed around these hard ground features. Banks and pinnacles provide important habitat for living organisms. Benthic biodiversity decreases with water depth and across the transition from the hard substrate of banks to soft sediment plains. Images: Geoscience Australia



ABOVE: **The Oceanic Shoals CMR contains components of three KEFs considered regionally important for biodiversity or ecosystem function and integrity: the carbonate banks and terraces of the Sahul Shelf and the Van Diemen Rise, and the pinnacles of the Bonaparte Basin. (Visualised depths fall between 0 and 300 m.)** Image: Geoscience Australia

growing awareness that Australia is a global diversity hotspot for sponges. Distinct regional faunas, including differences from east to west across the Oceanic Shoals CMR, and high levels of endemism are evident.

Shallower banks that rose to within 45 m of the sea surface supported greater biodiversity, including isolated hard corals of limited diversity. It is noteworthy that other studies of more seaward, clearer water shoals in the same CMR, undertaken in 2014 by AIMS, found much more abundant and diverse hard coral communities more similar to shelf edge shoals. This indicates the CMR boundary has captured a broad range of shoal and pinnacle features and associated environmental conditions, and the diversity of biota associated with these physical environmental gradients.

Tidal currents are important in shaping the seabed by scouring holes into soft sediments around the base of banks and pinnacles and by extending the length of pockmarks. Levels of suspended sediment (turbidity) appear higher in the western part of the CMR than the east, with some smaller pinnacles partly buried by sediment.

Demersal fish communities appear to correlate with the spatial patterns observed for the benthic biodiversity, occurring in larger and more diverse communities on the shallower, less turbid banks. Given that water clarity limited the utility of the demersal, camera-based methods deployed, better sampling of fish diversity across more turbid, mid-shelf regions of the CMR is likely to require extractive sampling such as trawls and traps. The surveyed area also supports a wide range of pelagic animals, with 32 species observed: 11 shark species, black marlin, barracuda, Olive Ridley turtle, sea snakes and orca.

New knowledge and opportunities

Biological samples collected in the Oceanic Shoals CMR clearly demonstrate the region's high biodiversity values. The abrupt bathymetric features such as pinnacles and shoals appear to be locations of species and biomass accumulation for macrobenthos, and other demersal and pelagic species relative to the broader shelf environs. The greater abundance of shoals than previously thought and the variety of their sizes, depths and shelf positions indicates a complex mosaic of biodiversity hotspots.

First qualitative models for the KEFs of Oceanic Shoals

Key Ecological Features (KEFs) are part of the marine environment considered regionally important for biodiversity or ecosystem function and integrity and are represented in the Commonwealth Marine Reserve Network. Qualitative modelling can be used to represent relationships between the physical and biological components of KEFs, and to assess potential threats.

New information gained from this Oceanic Shoals voyage made it possible for the first time to construct such models for its resident KEFs. The qualitative modelling was used to characterise ecosystem dynamics for the carbonate banks, terraces and pinnacles, and to predict future threats. It revealed no fundamental differences between terrace, bank and pinnacle communities, but the location of these features varied with respect to physical factors such as turbidity, water depth or shear stress associated with cyclones.

Attached invertebrate communities support fishes and mobile reef invertebrates through trophic interactions and habitat-effects, including refuge from strong currents and protection from predators. Invertebrate and plankton eating fishes are consumed by both benthic and pelagic predatory fish species. This latter predator-prey relationship links the benthic and pelagic ecosystems.

Based on the ecosystem structure, five key threats were considered plausible within a 50-year time frame. They included oil and gas spills, (affecting algae and planktivorous fishes), illegal fishing, (affecting benthic and pelagic piscivores), ocean acidification, (affecting tall algae), increased water column shear stress through increased storm intensity, and increased turbidity through increased agricultural run-off. The model, and the associated direct and indirect effects of the above five threats, will be used to identify ecological indicators of use to monitoring and management.

The research voyage extended understanding of biodiversity patterns on shoals into more turbid mid-shelf environs than previously assessed. The results confirm the importance of these features in supporting diversity, and elaborate the role of light reaching the seabed in shaping the dominant benthos. They also support the notion that as turbidity increases, the depth at which autotrophic species are able to dominate the seabed decreases. In the CMR this may be particularly the case for habitat-engineering species such as hard corals and large macroalgae. An opportunity exists to develop predictive models – based on data for depth, water quality and shelf position – to better understand the nature of benthic communities on the majority of shoal and pinnacle features yet to be surveyed.

Outputs and outcomes

This project exercised strong, national, multidisciplinary collaboration in marine science to build a greater understanding of marine connectivity, both within the CMR and across the broader region. It produced high-resolution bathymetry, geochemical and geophysical data, biological collections, and a new qualitative model of the KEFs of the Oceanic Shoals CMR. The results confirmed the value of the KEFs in terms of the biodiversity they host and their regional significance. They were communicated in scientific and non-technical formats, to raise the understanding of marine biodiversity in Australia's poorly known north and north-western waters, (including the potential effects of fishing, and oil and gas exploration and extraction).

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Analysis of approaches for monitoring biodiversity in the Commonwealth marine area: Houtman Abrolhos Islands

A suite of complementary, non-extractive survey methodologies is required to identify and monitor change in habitats and species across areas identified *by the Australian Government as Key Ecological Features (KEFs) of the marine environment.*

The Commonwealth marine environment surrounding the Houtman Abrolhos Islands is a KEF in the South-west Marine Region. This complex of 122 islands and reefs, some 60 km off the mid-west coast of Western Australia, form the largest seabird breeding area in the eastern Indian Ocean. Many of the islands' biodiversity features, most notably seabirds and rock lobster, are supported by benthic and pelagic ecosystems in surrounding Commonwealth waters.

The shelf rocky reefs in the vicinity of the Houtman Abrolhos islands mark the northern border of kelp, and the southern border of coral, in Australia. Because of this they are associated with very high biodiversity. Any changes in the distribution of kelp or corals in this region may signal climate-change induced shifts in species distribution. This project located shelf rocky reef coral-kelp communities that form part of this KEF, examined regional influences on gene flow between coral populations, and assessed isotope analysis of seabird feathers as a means of monitoring and evaluating changes in food webs.

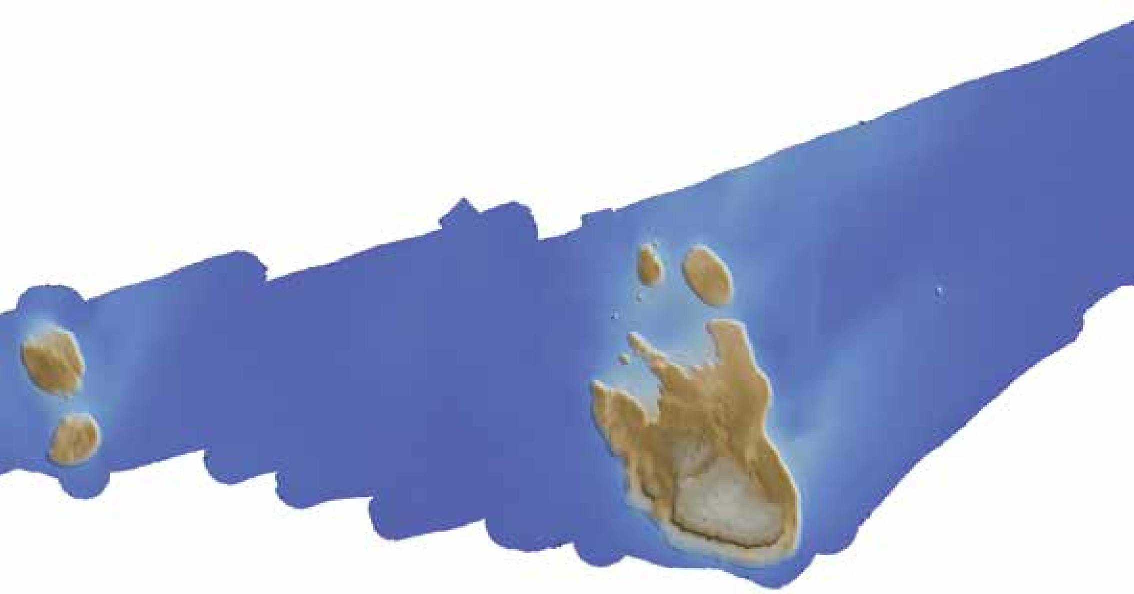
Approach

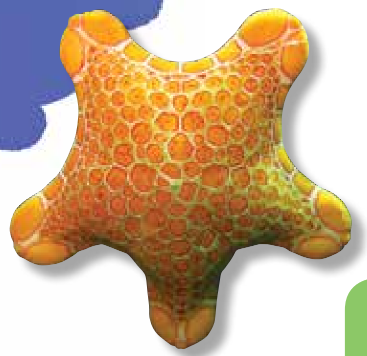
A survey designed using the Generalised Random Tessellation Stratified Technique (see story on page 51) identified the presence and patterns of benthic habitats in Commonwealth waters between the Houtman-Abrolhos Islands and the coast. Shelf rocky reefs (coral-kelp communities) in Commonwealth waters adjacent to the Houtman-Abrolhos Islands were located by a drop camera survey. Multi-beam sonar was used to delineate their boundaries. Integrated Marine Observing System autonomous underwater vehicles (AUVs) identified the presence/absence and abundance of coral, kelp and associated benthic communities.

The proportion of coral genetic variation (a key component of resilience) attributable to ocean circulation was determined by linking genetic data from a panel of coral microsatellites (short repeated DNA sequences at a particular locus on a chromosome) to a three-dimensional model that simulated coral dispersal over time.

A single tail feather (from each adult) and approximately 5–10 pin feathers (from each chick) were collected from two species of terns in a non-lethal and minimally-invasive way. Individual amino acids were extracted from the feathers and profiled using stable isotope analysis. Differences in the natural isotopic ratios for nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) were used to identify the bird's position in the food chain, as well as the sources of nutrients important for primary productivity.

ABOVE and ABOVE RIGHT: **Amino acids extracted from feathers provide information on the bird's trophic level, or position in the food chain, as well as the sources of nutrients important for primary productivity.** Images: CSIRO





Key findings

Shelf rocky reefs were located in the Commonwealth waters of this KEF (these had previously only been identified in State waters, but were predicted to be an important habitat of this KEF).

Stable isotope analysis enabled the feeding niches of sooty terns, bridled terns and crested terns to be differentiated for the first time. The results suggest that the absolute value of, and changes in, this nitrogen ratio may indicate the trophic level for several important seabird species, while the carbon ratio indicates the source of nutrients utilised by phytoplankton at the base of the food web. The technique may have potential for tracking fluctuations or trends in these variables over time providing a remote and cost-effective measure of the trophic status of offshore mid-water fish populations.

Regional oceanographic circulation patterns are a better predictor of gene flow between coral populations at the Houtman Abrolhos Islands than the distance (as the crow flies) between them.

New knowledge and opportunities

Shelf rocky reefs, previously unknown, were located in the Commonwealth waters of this KEF, and the composition of coral-kelp communities will be characterised during the analysis of AUV imagery.

Analysis of compound-specific stable nitrogen isotopes extracted from bird feathers was demonstrated as a possible cost-effective monitoring tool for offshore pelagic ecosystems which would enable the long-term monitoring of ecosystem health for this pelagic productivity KEF. The technique could be combined with new approaches to evaluating population-level plastics ingestion and identifying foraging habitats of seabirds.

TOP: **High resolution bathymetry of a shelf rock reef in Commonwealth waters adjacent to the Houtman Abrolhos Islands, derived from multibeam sonar swath.** Image: CSIRO

TOP RIGHT: ***Pentagonaster dubeni* (seastar) in 8 m coral reef habitat at the Houtman Abrolhos Islands.** Image: IMAS/Reef Life Survey

ABOVE: **Parrotfish school over typical reef habitat in depths of 10–20 m at the Houtman Abrolhos Islands.** Image: Reef Life Survey.

ABOVE RIGHT: **A Spangled Emperor (*Lethrinus nebulosus*) at 0–15 m depths.** Image: IMAS/Reef Life Survey

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Analysis of approaches for monitoring biodiversity in the Commonwealth marine area: Solitary Islands

An important part of establishing monitoring protocols is to determine the optimum sampling regime for seabed biodiversity.

This project inventoried shelf rocky reef habitats, benthic communities and demersal fish at the temperate Shelf Rocky Reef Key Ecological Feature (KEF) near the Solitary Islands off New South Wales. Underwater imaging equipment was tested and improved during the process, and protocols were developed to improve the efficiency and rigour of future monitoring.

Approach

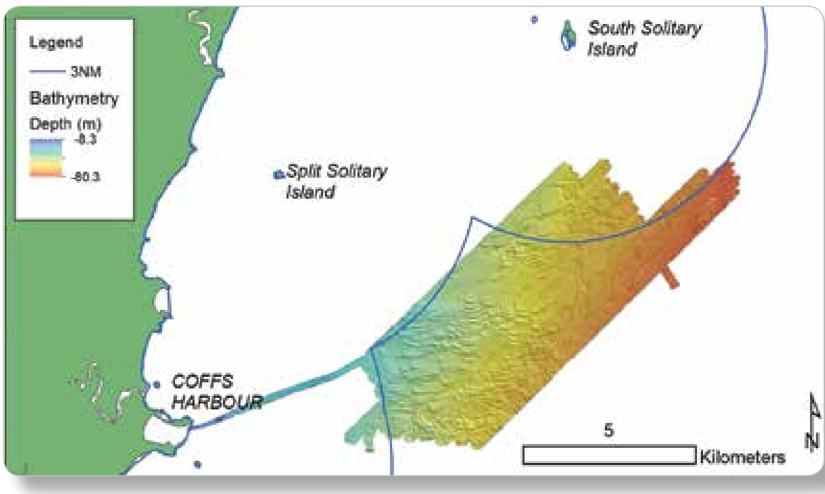
Non-extractive survey methodologies were developed, deployed and evaluated under a range of conditions. In addition, an experimental, two-day deployment of 30 baited remote underwater video (BRUV) systems located at varying distances apart examined spatial autocorrelation (the degree of clustering) between observations of selected fish assemblages. This evidence will help to determine the minimum distance between BRUVs at which samples are statistically independent and therefore useful for detecting trends. The effect of habitat characteristics (such as reef rugosity) on fish communities was also examined.

Key findings

High-resolution multibeam sonar swath mapping and analysis of 40 km^2 of seafloor habitat identified ancient-coastline reefs and mobile sands on the seafloor south of South Solitary Island. The abundance of fish at every trophic level was strongly related to the three-dimensional structural complexity of reefs: generally, abundance increased with complexity. At small-scales, complexity influenced the abundance and composition of four of the five trophic groups examined.

Data from the experimental BRUVs deployment proved inconclusive, so the project team analysed a much larger data set from Queensland's Moreton Bay. Initial model results indicated that the spatial correlation between observations of snapper was negligible after about 300 m (indicating that for statistical efficiency in these areas BRUVS should be placed at least 300 m apart).

The project examined how to streamline the manual scoring process of complex, underwater video images, and defined a 'stopping rule' after which little further information would be gained by further analysis. With 25 points per image, 20 images were sufficient to characterise benthic biodiversity in the Solitary Islands KEF.



ABOVE: **Additional multibeam sonar data acquired in the Solitary Islands KEF.** Image: CSIRO

ABOVE: **Thicklip Trevally (*Carangoides orthogrammus*), Solitary Islands.** Image: Reef Life Survey

New knowledge and opportunities

The distribution and importance of rocky reefs in this area appear to part of a larger complex of reefs associated with ancient coastlines that occur around Australia.

Fine-scale BRUV data on the distribution of selected fish are being combined with broader-scale (swath acoustic) mapping to predict the occurrence of different species over the broader area of the KEF that will be useful in determining its ecological values and status.

Some 30,000 image labels have been provided to University of Sydney researchers to 'train' supervised automatic image classification algorithms.

Outputs and outcomes

This project has generated an improved understanding of the location and morphology of shelf rocky reefs in Commonwealth waters near the Solitary Islands and key determinants of demersal fish community composition in this KEF. It has inventoried demersal fish and benthic communities and identified effective methods of design, collection and analysis of underwater imagery in rocky reef habitat.

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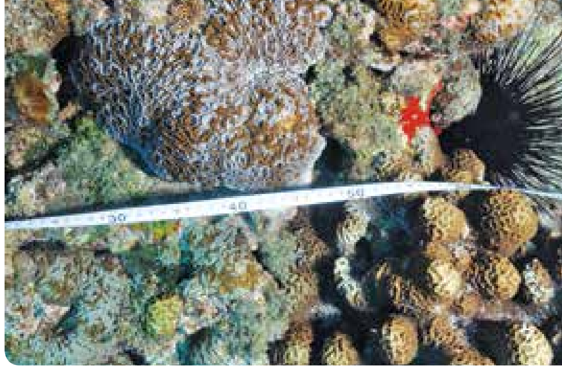


Putting names to a sea of faces

Photographs and video provide a safe, non-destructive and efficient way to examine and monitor marine habitats, and are particularly useful in areas protected for their biodiversity values.

To be useful on a national scale, however, the life forms they reveal must be named in a consistent way. This project established a national standard for classifying the substrates, flora and fauna visible in marine photos and video. The Collaborative and Automated Tools for the Analysis of Marine Imagery (CATAMI) classification system now provides that common vocabulary for Australia.

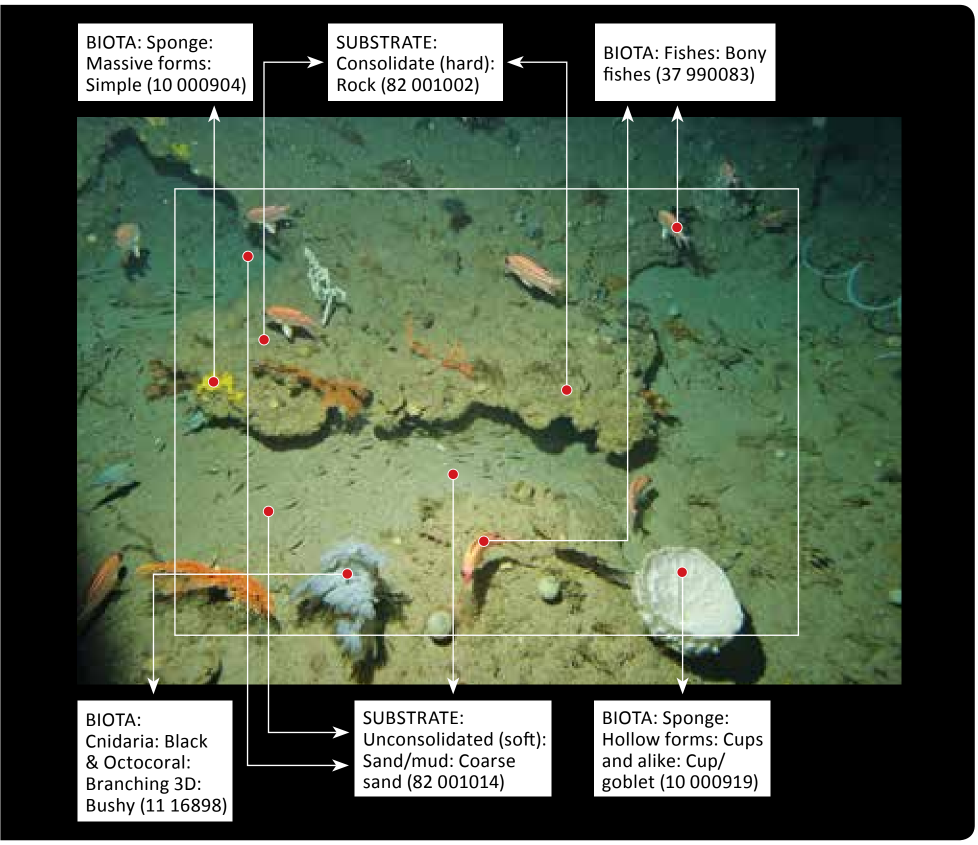
Approach

The CATAMI classification system (CSS) was funded by the National eResearch Collaboration Tools and Resources and supported by the Australian National Data Service. It was established and refined during workshops involving software engineers, programmers, and benthic ecologists from state and Commonwealth agencies and universities, under the direction of the CATAMI Technical Working Group. For longevity, the CCS was incorporated into the Codes for Australian Aquatic Biota database.

New knowledge and opportunities

The CCS employs a standardised combination of high-level taxonomy (phylum, order, class) and morphological (shape, growth-form) characteristics that can be determined from a picture. This provides more consistency than traditional classification approaches. In future, the system could be combined with automated image analysis to ensure the consistent annotation of datasets used to 'train' automatic image analysis algorithms.

BIOTA COMMUNITY: OUTCROPPING ROCK AND SEDIMENT POCKETS WITH SPARSE SPONGE AND OCTOCORAL COVER



The CCS provides the framework for nationally-consistent annotation of marine imagery data. This will support national marine monitoring by streamlining data collated by different organisations, including through government contracts, environmental impact assessments and long-term monitoring.

Outputs and outcomes

An agreed, national standard for classifying substrates and biota in marine imagery has been developed and provided online through the Australian Ocean Data Network. Standardised, quantitative estimates such as the presence and percentage cover can now be made from video and photographic images, improving the efficiency of marine ecosystem research and the ability to compare results from different studies.

The CCS is being adopted by industry, government and academia, with several hundred copies of the technical document and code file downloaded from the website. It has been used by the NERP Marine Biodiversity Hub, the Reef Life Survey, the New South Wales Marine Protected Areas monitoring program, the Australian Institute of Marine Science, and the Australian Centre for Field Robotics, and in two online annotation tools: CATAMI and Squidle. Environmental consultants to oil and gas companies (GeoOceans and Chevron Wheatstone Project) have also used the CCS. An illustrated CATAMI poster is publicly available.

TOP: **A combination of coral functional groups, turf algae, and urchins at Middleton Reef in the Lord Howe CMR.** Image: IMAS

LEFT: **Taxonomic and morphological characteristics are combined in the CATAMI system to ensure standard annotation of marine imagery data.** Image: CSIRO

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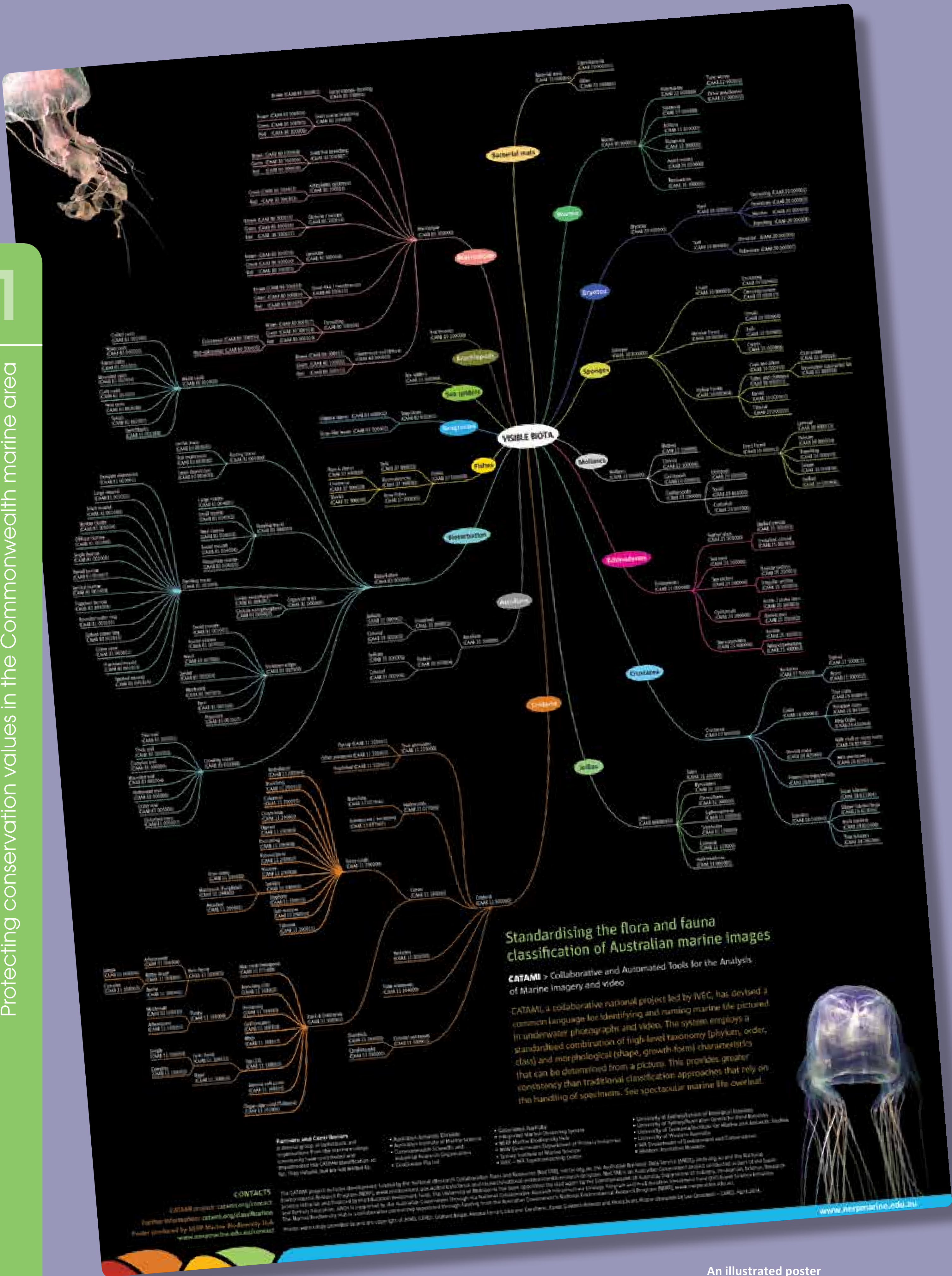


An illustrated poster highlights features of the CATAMI classification system.

www.catami.org/classification

Marine monitoring blueprint: meeting a monumental challenge

Australia's Commonwealth waters support a range of marine biodiversity, ecological features and processes, and contribute to the economy through fishing, energy and tourism industries.

Monitoring this environment is an enormous challenge, and the Department of the Environment has been investing since 2008 in Australia's capacity to report on the health of the Commonwealth Marine Area (CMA). The investment is fostering new approaches to characterising and analysing marine areas – including environmental pressures, and monitoring change – by government agencies, research organisations and industries.

This project provided direction for the staged implementation of a monitoring program to meet the Department's reporting needs. Existing marine conservation values (Key Ecological Features, or KEFs) identified by the Australian government were considered together with the requirements, options and constraints associated with building a national monitoring program. A central question was whether a sufficient evidence base existed to support State of the Environment reporting on the health and trends of KEF habitat, features, processes and pressures.

Approach

Eight years of research on ecological indicators and monitoring for the CMA were synthesised to begin clarifying the drivers and interests that motivate the Department to seek information on marine ecosystem health. A search engine known as ARMARDA (see story on page 26) was built to assess the major marine databases in Australia. Existing data relevant to monitoring KEFs were summarised to identify opportunities for use in determining status and trends, and information gaps. Finally, Australia's capacity (governance and functional) for monitoring KEFs was reviewed.

Key findings

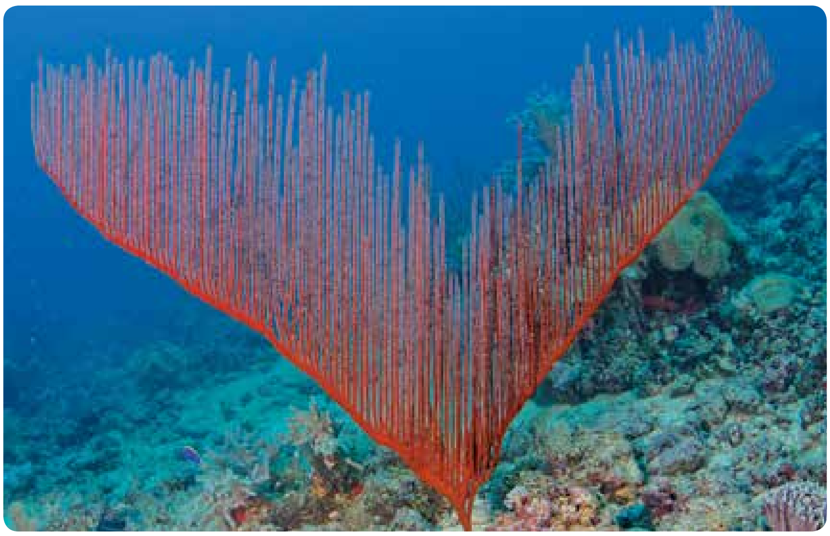
The Department seeks to improve the monitoring of marine ecosystem health in the CMA through a focus on KEFs. Fifty-four KEFs have been identified across Australia's six bioregional marine planning areas (not including State waters or the Great Barrier Reef Marine Protected Area). Based on the existing scientific understanding of marine ecosystems and their response to pressures, suites of physical and biological indicators have been identified for 33 KEFs.

KEFs represent areas of significant biodiversity or ecological functioning and integrity within Commonwealth waters. The monitoring of KEFs therefore will provide an evidence base to support decision making to conserve and protect the Commonwealth marine environment. It will also strengthen the quality of environmental reporting on the status and trends of marine health, such as that undertaken for State of the Environment reporting.

Governance mechanisms that provide leadership, oversight and coordination for KEF monitoring have not been established. Establishing an initial oversight and coordination group is an important step in transitioning from KEF research to prioritised operational KEF monitoring.

Existing data within KEF boundaries date back to the 1950s and mainly cover physical data used to understand ocean circulation. Most scientific biological sampling has occurred for KEFs associated with shelf reefs and areas of enhanced pelagic productivity. This combined with satellite data is likely to initiate monitoring baselines for some KEFs. Limited data have been collected for KEFs associated with seamounts, but further work is needed to gauge their value to monitoring. Relatively few biological datasets have been collected for KEFs associated with submarine canyons, unique features of the deep sea, and shelf sediment basins.

Australia's marine observing community has the capability to deploy ocean observing equipment to generate new monitoring data for KEFs, including visual and video-based methods, acoustic and remote sensing methods and physical sampling. Methods with a relatively long history of deployment – such as diver visual census, active fishing gears,



ABOVE: **KEFs represent areas of significant biodiversity or ecological functioning and integrity within Commonwealth waters.**

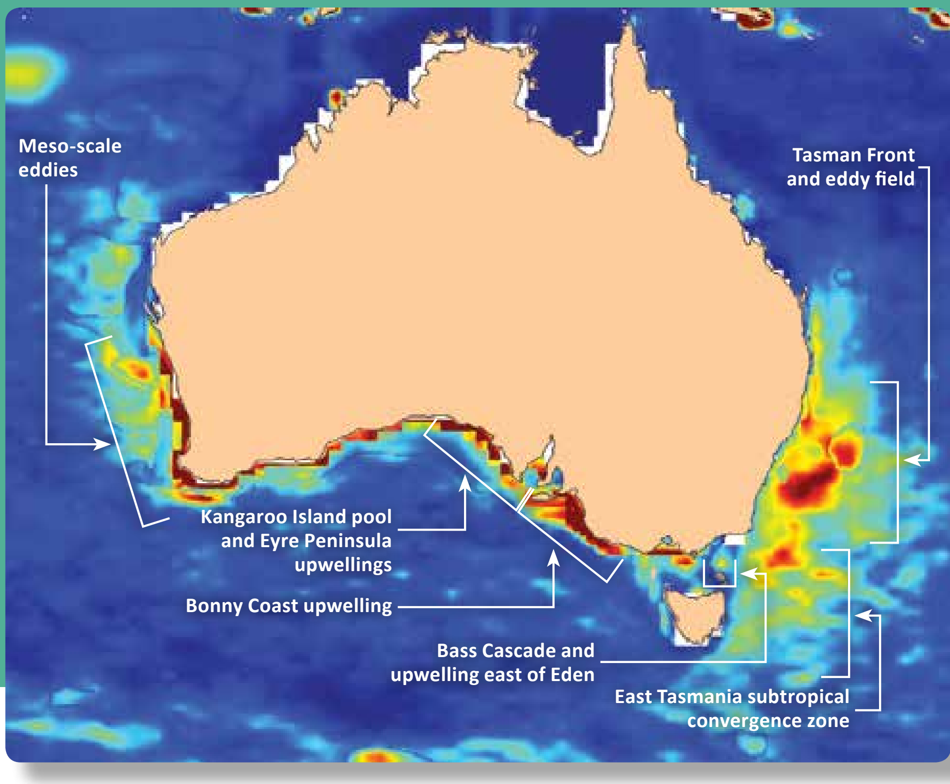
Streamlining marine monitoring indicators

Indicators for marine ecosystem monitoring have proliferated in the past two decades, presenting significant challenges integrating and reporting indicator data at regional or national scales. To help overcome this problem, Marine Biodiversity Hub scientists, in collaboration with policy makers, have grouped KEFs and identified suites of indicators for these groups. The six reporting groups are: ecosystems associated with canyons; deep seabeds; areas of enhanced pelagic productivity; seamounts; shelf reefs and shelf seabeds.

This figure shows the approximate location of nine KEFs in Commonwealth waters that can be grouped to guide regional and national scale reporting on the status of and trends in areas of enhanced pelagic productivity.

The location of the KEFs aligns closely with the results of a national pelagic productivity analysis based on three productivity generating processes – upwelling areas (dominated by eddies), frontal density (thermal fronts) and eddy kinetic energy – completed independently of the KEF-identification process. In this example, there is a high degree of similarity among the indicators identified for each of these KEF systems: for example, nutrients and phytoplankton indicators are common to the vast majority of KEFs in this group and upwelling and seabirds indicators are common to at least three of these KEFs.

APPROXIMATE LOCATIONS OF KEY ECOLOGICAL FEATURES IN COMMONWEALTH WATERS



RIGHT: **The KEF systems indicated here share a range of common indicators.**

and earth observing satellites – experience the least constraints (such as cost, ease of deployment, and maturity of data processing and analysis).

The Department will require data management arrangements for KEF monitoring and will need to clarity its role in managing KEF indicator data. The Australian Ocean Data Network enables Australian government agencies and stakeholders to share and link KEF monitoring data. The Bureau of Meteorology National Environmental Information Infrastructure provides reference architecture for enhancing the discovery, access and use of national environmental information and should be used to configure data management arrangements for KEF indicator data. Information products for KEF monitoring will need to be specified after monitoring priorities are identified.

The marine monitoring blueprint identifies that Australia has the ecosystem understanding and practical capability necessary to begin KEF monitoring. Vision, governance and clear prioritisation will be important elements of the establishment phase.

New knowledge and opportunities

A foundation has been laid for a more strategic approach to understanding and monitoring marine ecosystem health that builds on past and present research investment. The majority of the KEFs share common ecological systems, and can be grouped to facilitate regional or national environmental reporting. Discussion between scientists and policy makers identified six reporting groups: for ecosystems associated with canyons, deep sea beds, areas of enhanced pelagic productivity (see story above), seamounts, shelf reefs and shelf seabeds.

Outputs and outcomes

This project has produced a blueprint for improving the monitoring of marine ecosystem health in the CMA with tools including a KEF atlas and KEF database identifying existing data, models and indicators. It has fostered a collective understanding among policy makers and scientists of Australia's marine monitoring capacity, and of how this capacity can be improved through continued collaboration.

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Supporting the recovery of threatened, endangered and protected species

2

IMAGE: Russell Bradford, CSIRO

The need

Species that are listed as threatened, and migratory species listed under international agreements are protected as matter of national environmental significance under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*).

The Australian Government seeks to develop targeted collaborative programs to coordinate species recovery and environmental protection efforts across Commonwealth, State and Territory agencies with responsibilities for the marine environment. It also seeks relevant, accessible and evidence-based information to support decision-making associated with development proposals. The task of protecting listed species, however, is challenged by the number of species involved, and the number for which insufficient data are available to develop or measure progress against species recovery plans.

Marine species are listed under the *EPBC Act* in all categories from critically endangered to conservation dependent, and across most taxa including bony fish, cartilaginous fish, seasnakes, turtles, mammals, birds, and invertebrates. It is difficult to estimate the abundance of most of these species because they are typically both rare and widely distributed; for some species, such as the Largetooth Sawfish or Speartooth Shark, adults are rarely or never observed.

New methods are needed to assist with species recovery plans, to support managers in decisions relating to new development and non-detriment findings for the export of CITES-listed species, and to support international obligations. Marine Biodiversity Hub scientists, building on recent developments to estimate the abundance of over-exploited commercial fish populations, developed new genetic approaches combined with acoustic telemetry to estimate abundance and determine movement patterns and habitat use. These were applied to threatened river sharks in the Northern Territory, even when no adults could be directly sampled. The goal was to develop an effective and affordable technique that could be used for other rare and threatened mobile species.

Following the recent shark attacks in Western Australia attributed to White Sharks, the Australian Government requested Hub scientists to apply these new methods to estimating the abundance of the White Shark (eastern and western populations) as well as the Grey Nurse Shark (eastern population).

IMAGE: Michelle Jonker, AIMS

Populations and habitat use of euryhaline sharks and rays

Populations of sawfishes and river sharks in the Northern Territory are thought to have declined dramatically in recent decades, raising concerns about their viability.

The Largetooth Sawfish, *Pristis pristis*, and the Dwarf Sawfish, *P. clavata*, are listed as Vulnerable under the *Environmental Protection and Biodiversity Conservation Act 1999*; the Speartooth Shark, *Glyphis glyphis*, is Critically Endangered, and the Northern River Shark, *G. garricki*, is Endangered. More information is needed about the distribution, ecology and population dynamics of these species to assist in their conservation, management and recovery. This project generated a better ecological understanding of the habitat use and habitat requirements, short and long-term movements, connectivity and spatial dynamics of these priority euryhaline elasmobranch species and collected tissue samples to enable abundance estimation with close-kin mark-recapture. The improved understanding has contributed to the multi-species Recovery Plan for Sawfish and River Sharks being developed by the Department of the Environment.

Approach

Fisheries-independent surveys in selected river systems were conducted using appropriate sampling gear (primarily gillnet and rod and line). Captured sharks were tagged and monitored with active and passive acoustic telemetry. Active tracking involves mounting a hydrophone to a tracking vessel to follow fish movement patterns and habitat use in real time (short-term telemetry). Passive tracking uses networks of moored acoustic receivers to detect tagged fish when they pass within range of a receiver (long-term telemetry).

Extensive arrays of acoustic receivers (130 receivers) were deployed in seven Northern Territory and Queensland river systems to provide long-term monitoring of tagged animals (some 400 individuals from 10 species tagged).

ABOVE: **A Largetooth Sawfish caught in the Adelaide River. Floodplain billabongs were found to be nursery areas for juvenile Largetooth Sawfish on the Daly River. The very low catch of animals aged one year and above suggests that few juveniles survive more than a year.**

LEFT: **Peter Kyne checks an acoustic receiver from the West Alligator River. Extensive arrays of acoustic receivers were deployed in seven Northern Territory and Queensland river systems to provide long-term monitoring of tagged animals.**
Images: Michael Lawrence-Taylor, Charles Darwin University

Mitochondrial genome sequencing of Speartooth Sharks and Largetooth Sawfish was used to help profile their population structure. The mitogenome, which is inherited through the mother, offers clues to how widely the females are dispersing to breed (for example, between river systems). Complete mitochondrial genome sequences have been published for the four sawfish and river shark priority species (as well as for a suite of other coastal and estuarine sharks and rays of northern Australia).

Key findings

Largetooth Sawfish, *P. pristis*

Catch per unit effort (CPUE) was used to compare catches of fish species (such as the number of sawfish caught per 100 m of gillnet per day) between surveyed rivers. Low catch rates were recorded throughout the NT, although the CPUE of neonates (newborns) in the Adelaide River was comparable to the Fitzroy River (WA) which is a key nursery area for *P. pristis*. (Fitzroy River data published by Murdoch University.) Catches were dominated by sawfish less than one-year-old (the 0+ age-class). The very low CPUE of animals aged one year and above is of concern, suggesting that few juveniles survive more than a year. Floodplain billabongs were found to be nursery areas for juvenile *P. pristis* on the Daly River.

Analysis of mitochondrial DNA revealed strong population structuring of *P. pristis* across northern Australia: except for rivers flowing into the Gulf of Carpentaria, all river drainages appeared to host a genetically distinct population. This means there is limited capacity for the re-colonisation of localised populations that are depleted due to juvenile and adult mortality (at least for females at this stage).

Dwarf Sawfish, *P. clavata*

Limited numbers of *P. clavata* were recorded during the project, mainly due to a lack of fishing effort in its core habitat of coastal and estuarine areas (most sampling for sawfish was undertaken in mid-upstream reaches of rivers to target *P. pristis*). All known records of *P. clavata* in the NT were reviewed and mapped, but the species remains poorly known in the NT. Records from mid-reaches of rivers demonstrate the use of this habitat as nursery areas for juvenile fish.

Northern River Shark, *G. garricki*

Populations of *G. garricki* were found in the Van Diemen Gulf area (in particular Kakadu National Park's Alligator Rivers region), and in more rivers than had been documented previously. Catch rates were high in all rivers, with more than 350 individuals recorded (before this project only eight records existed from the NT). This species' distribution is still limited to less than 10 rivers and estuaries, however, and uncertainty remains over its abundance elsewhere in its range (such as the Kimberley region of Western Australia). The degree of population structuring between rivers and regions across its distribution is also unknown.

Movement data show highly seasonal distribution patterns within the South Alligator River (where 50 sharks were acoustically tagged for long-term telemetry studies). In the dry season, animals were located mainly 40–80 km upstream; in the wet they remained around the river mouth, with limited movement to adjacent rivers.

Speartooth Shark, *G. glyphis*

G. glyphis catches were highest in the Adelaide River, with the South Alligator River and Queensland's Wenlock River also supporting reasonable catches. Movement patterns were similar to *G. garricki* with a downstream migration in the wet season and animals confined to narrow (20–40 km) stretches of river during the dry season.

Analysis of mitochondrial DNA revealed a strong catchment-level separation of all known Australian *G. glyphis* populations (Adelaide River, Alligator Rivers, Wenlock River) which has important management implications.

ABOVE: **Little is known about Dwarf Sawfish in the Northern Territory.** Image: Peter Kyne, Charles Darwin University

RIGHT: **Fieldwork on the Adelaide River. Catches of Speartooth Shark were highest in the Adelaide River, with the South Alligator River and Queensland's Wenlock River also supporting reasonable catches.** Image: Mat Gillfedder

Each population can be considered a separate management unit, with limited capacity of adjacent populations to repopulate another population were significant declines to occur.

New knowledge and opportunities

Research infrastructure and capabilities developed during this project will support ongoing monitoring and assessment, with acoustic receiver arrays established in the Adelaide and South Alligator Rivers providing an opportunity for long-term monitoring of sawfishes and river sharks. The existing *G. garricki* tissue sample collection provides the opportunity to assess population structuring across the range of this species (when combined with required surveys of further key rivers).

The occurrence and habitat of adult *G. glyphis* remains unknown. There is a need to explore how advancing tagging technologies could be applied to find adult populations. Large sub-adults (locatable in key rivers at certain times of year) could be fitted with satellite tags, and larger fishing gear such as set longlines could be trialled to catch (and then tag) adult females at pupping time. (Pupping period has been determined based on the presence of pups in rivers.)

The project demonstrated the benefits of combining the disciplines of field ecology and quantitative genetics. Recent developments in technologies for both disciplines have given rise to the quantitative information on population dynamics and habitat use that will guide management decisions affecting these rare species.

Number of samples collected for close-kin mark-recapture for NERP Marine Biodiversity Hub	
Speartooth Shark (NT rivers)	233
Speartooth Shark (Wenlock River, Qld)	102
Largetooth Sawfish	65
White Shark	314
Northern River Shark (for future application)	365

Outputs and outcomes

This project generated improved understanding and knowledge to support the management and recovery of threatened sawfishes and river sharks. Expert advice was regularly provided to the Department. This included contributing to assessments of proposed developments for their potential impact on threatened species (referrals), and to developing a Recovery Plan for Sawfish and River Sharks.

Species information sheets were developed and published for the four species studied. A guide to the sharks of Kakadu rivers, and protocols for surveying and tagging sawfishes and river sharks were also published. More than 10 scientific manuscripts have been produced, and a greater number are being prepared or planned.

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BELOW: **A Northern River Shark caught in the West Alligator River. This species was found in more Northern Territory rivers than had been documented previously, but its abundance is uncertain elsewhere in its range.** Image: Michael Lawrence-Taylor

Partnering with indigenous communities

Largetooth Sawfish (*Pristis pristis*), Speartooth Sharks (*Glyphis glyphis*) and Northern River Sharks (*Glyphis garricki*) are being studied in the Top End to learn more about their distribution, ecology and population status.

Indigenous people are major land and sea custodians and managers in northern Australia where these species occur. Indigenous communities and rangers have been helping NERP Marine Biodiversity Hub scientists with their research, providing guidance, practical assistance and access to Indigenous lands, as well as building skills and employment opportunities. The partnership is essential to furthering the understanding and management of threatened sawfishes and river sharks in the Northern Territory. Hub scientists aim to engage further with Indigenous communities when projects are of mutual interest.

Approach

The research team worked with Indigenous communities, Traditional Owners and rangers to survey for sawfishes and river sharks in the Daly River region and the Alligator Rivers region of Kakadu National Park. The collaboration provided employment and skill transfer opportunities to Indigenous communities participating in sawfish and river shark research.

As well as fostering opportunities for Indigenous employment and capacity building, the project sought to jointly identify opportunities to build on Indigenous knowledge, to ensure the effective and ethical communication of research outcomes to Indigenous communities, and to provide opportunities for Indigenous participation in project development. These guiding principles were borrowed from the Indigenous Engagement Strategy developed by the NERP Northern Australian Hub.

Key findings

Partnering with the Malak Malak Traditional Owners and Ranger Group provided unique opportunities to access Indigenous lands to survey sawfish habitat. This included the first application of environmental DNA (eDNA) survey techniques on threatened elasmobranchs, and on floodplains. (The eDNA technique use traces of DNA in water to detect the presence of species that occur there, through the collection and analysis of water samples and was a collaboration with the NERP Tropical Ecosystems Hub.)

Traditional knowledge of sawfish habitat provided evidence for the previously-unrecognised importance of off-stream floodplain billabongs for sawfishes in the Daly River region.

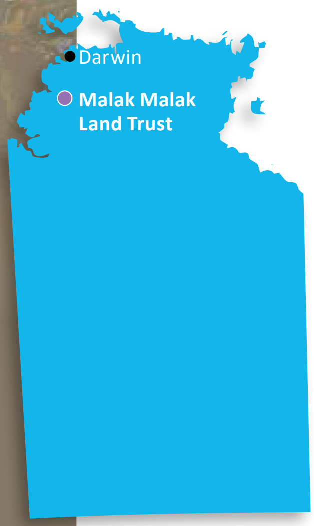
Access to the co-managed (Traditional Owners and Parks Australia) Kakadu National Park facilitated extensive research on the river shark populations of the Alligator River region. Indigenous employment opportunities were provided to local communities in Kakadu, with participants becoming key field personnel.

New knowledge and opportunities

Indigenous communities and ranger groups in northern Australia are uniquely placed to partner in research on threatened species and many opportunities exist to undertake research on aquatic, coastal and marine systems. Future surveys and genetic tissue sample collection of threatened sawfishes and river sharks will benefit from partnerships with Indigenous communities and ranger groups. Of particular value is the exchange of knowledge between western scientific research and management priorities, and traditional knowledge and management priorities. Advancing technologies supporting data collection on country will

LEFT: **Billabong sawfish gillnetting on Malak Malak country, Daly River.** Image: Peter Kyne

Saving sawfish in the Daly River



Malak Malak Indigenous rangers and Traditional Owners have a unique understanding of sawfish habitats in the Daly River region, and have helped scientists to locate important floodplain areas that act as nursery areas for young sawfish. In September 2012, as Top End floodplains were drying, the rangers raised the alert when Largetooth Sawfish (*Pristis pristis*) were stranded in a shallow waterhole near the Daly River. The team of researchers, rangers and Traditional Owners subsequently netted nine sawfish and two barramundi, and returned them to the river. Two weeks later the waterhole was dry. Largetooth Sawfish are born at the river mouth then move upstream, often spreading out into floodplain billabongs, but sometimes they can pick the wrong one. While the floodplains can be productive, fish can perish if the billabongs dry out before the following wet season, due to late rains or a hot, dry season. Images: Amos Shields, Malak Malak Ranger Group

assist future integration of traditional knowledge (specifically, occurrence of critical habitat) and threatened species management.

Outputs and outcomes

Working with Indigenous communities in the Daly River region led scientists to discover the importance of off-stream floodplain billabongs for sawfishes, and drying floodplain billabongs were surveyed annually between 2012 and 2014 at the end of the dry season. The partnership also worked to save a group of juvenile sawfish that otherwise would have perished. Nine sawfish were relocated from a rapidly drying waterhole on the Malak Malak Land Trust to the main river channel in 2012, after scientists were alerted by Traditional Owners and Indigenous Rangers (see story at left).

Employment was provided to several Indigenous community members during river shark and sawfish research in Kakadu National Park. Two publications were initiated that highlighted the natural values of Malak Malak country. The booklet *Sawfish on Malak Malak Country* is in preparation in partnership with the Malak Malak Ranger Group, and the brochure *Migratory Shorebirds of Tyumalagun, Malak Malak Land Trust* was published in partnership with Malak Malak Traditional Owners and the NERP Northern Australian Hub.

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White Shark population and abundance trends

Supporting the recovery of threatened, endangered and protected species

2

Evidence-based information is needed to address high-priority actions in the National Recovery Plan for the White Shark (*Carcharodon carcharias*) to underpin population and risk assessments, and to support local-scale policies and management.

This project developed, tested and applied tools for estimating the abundance and population status of White Sharks in Australian waters, including the first ever empirical estimate of adult White Shark abundance. Elements of this task included confirming population structure, identifying habitats, developing measures of key population attributes, and improving information on movement patterns. This built on research data gathered in the past decade.

Approach

Genetic data from individual sharks were analysed to identify sibling relationships, (sharks that share one or both parents), the most informative of which are half-sibling pairs from different birth-years. Genetic-based mark-recapture analysis provided the first empirical estimates of adult abundance and the basis for estimating reproductive frequency and adult survival. It also shed light on population structure (see story on page 46).

Acoustic tags (5–10 year duration) and satellite tagging were used to trace movement patterns (including residency and depth-swimming behaviour), identify habitats, examine growth rates, and further explore population structure. Aerial and vessel-based surveys at nursery areas were trialled to provide estimates of juvenile abundance. These data support a population model being developed to estimate total population abundance and population trend for eastern Australia.

Key findings

Detections of acoustic-tagged juvenile sharks continue to provide movement data and, over time, will provide survival estimates. Juveniles were recorded on 273 acoustic receivers spanning the eastern Australian coast, from Lady Elliott Island in the southern Great Barrier Reef to Flinders Island off north-eastern Tasmania (more than 179,000 detections). A shark tagged in New South Wales was detected on receiver arrays in New Zealand and several sharks tagged by New Zealand colleagues were detected in eastern Australia. These data highlight the utility of broad-scale acoustic receiver arrays deployed under the Integrated Marine Observing System and data-sharing between partner institutions.

Tagging data continue to support a two-population model for White Sharks in Australia, separated east and west by Bass Strait, and the migration of juveniles along the eastern seaboard between eastern Tasmania/south-eastern Victoria and the southern Great Barrier Reef. They provide further evidence of shark movements between eastern Australia and New Zealand, and multi-year return and occupancy of two known east coast nursery areas (Port Stephens, NSW and 90 Mile Beach-Corner Inlet, Vic).

Tagging data predict a higher level of movement and potential for gene flow (or transient movement of non-breeding sharks) between Australia and New Zealand than between the east and west of Bass Strait.

Tissue samples were collated from 331 White Sharks (129 'eastern population', 185 'western population' and 17 from New Zealand). Genetic analyses have identified half-sibling and full-sibling sharks in the relatively limited number of east coast samples. Adult population size for eastern Australia was estimated at 750–1200 individuals; further analyses will improve this estimate. Genetic data also support the two-population structure across Australia, with a low interchange rate between populations. These data will provide the first empirically derived estimates of reproductive frequency and, with further sample analysis, adult mortality rates. These measures are needed for population models to estimate total population sizes for juveniles and adults, and to assess the relative and cumulative effects of mortalities over the whole life span.

ABOVE: **Acoustic and satellite tagging were used to trace White Shark movement patterns, identify habitats, examine growth rates and explore population structure.** Image: Justin Gilligan, NSW DPI

The finding of half-sibling matches in a small number of sharks (51) analysed as a trial from the western population suggests the size of this population may also be estimated in future (with further sample analyses and refinements).

Tagging of adults in South Australia combined with vessel-based and aerial surveys of the southern Australian coast are providing the first evidence for nursery areas west of Bass Strait.

New knowledge and opportunities

Tools developed in this project provide for the first empirical estimates of adult population size of a highly vagile threatened marine species. They provide the basis for effective monitoring that could be applied to assess other marine species for which population data are poor. Further refinements of the genetic technique will enable estimates of single-generation abundance trends, without the need for long-term monitoring. This represents a paradigm shift in the capacity to define conservation needs for this and similar threatened species.

Opportunities exist to improve knowledge of the western White Shark population (including identifying nursery areas), to continue tissue sampling tagged sharks, and to apply the integrated genetic analysis and modelling approach to estimate population size and status. A similar approach is now being applied to the Grey Nurse Shark and could be applied to other species of concern such as the Mako Shark, the Dugong, and turtles.

Outputs and outcomes

This project has developed the first empirically-derived adult White Shark population estimates (worldwide) and provides the basis for estimating measures of key population attributes (reproductive frequency, survival rates) needed to estimate population trends. It has identified key habitats in eastern Australia and laid the groundwork for estimating total population size and status in Australian waters.

Science-based advice was provided to support conservation actions, management of shark-based tourism, and policy regarding public safety. In the government sphere, advice has been provided to Federal and State agencies, departments and ministers (including the Environment Protection Authority of Western Australia, the Federal Department of the Environment, New South Wales Department of Primary Industries and the South Australian Department of Environment, Water and Natural Resources).

Reports and journal papers have been generated on topics including novel genetic techniques for estimating population parameters, mark-recapture modelling, tagging and tracking, movements and aggregations, habitat, and health.

ABOVE: **Acoustic-tagged juvenile sharks continue to provide management data and, over time, will provide survival estimates to support a White Shark population model.** Image: Justin Gilligan, NSW DPI

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Estimating population size and characteristics of rare and endangered species

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Advanced genetic and statistical techniques have been combined to develop a reliable way of monitoring rare but wide-ranging species such as sharks and sawfish and has the potential for extension to other species including dugongs and turtles. The method has evolved from a simpler version developed by CSIRO in 2012 that now underlies the management of Southern Bluefin Tuna. It is based on 'mark-recapture': the principle that if some animals in a given area are caught and marked, the proportion of animals in a later, second round of captures that are caught twice can be used to estimate the total population.

The new monitoring technique extends the mark-recapture principle to use natural genetic 'marks' to identify animals that are close-kin pairs (full or half-siblings, or parent and offspring). These paired relationships are identified from tissue samples taken from live or dead animals. Importantly, because the mark is a natural piece of the inherited DNA, no first round of captures to place artificial marks is required.

The ability to find half-siblings (that share the genetic mark from only one parent) has only become possible in the past five years thanks to improved genetic technology, and it means that juvenile samples can be used to study the adult population. This is a breakthrough for many sharks and sawfish species for which adults cannot be caught in large numbers. Data from other sources such as acoustic tagging provide additional information on factors including age-specific mortality rates and movement patterns. Where feasible, these data can supplement the close-kin population estimate to pinpoint when and where population-limiting mortality occurs.

Key challenges tackled during this project have been to improve the reliability of the genetic techniques and to devise a statistical and demographic framework for close-kin mark-recapture that incorporates information from additional sources. The good news is that the genetic techniques appear to be working. Dozens of full and half-siblings have been identified among hundreds of Speartooth Shark and White Shark samples, and for these two species sufficient data exist to make preliminary abundance estimates.

Besides adult abundance, other parameters that can be estimated from close-kin mark-recapture include adult survival rates, breeding frequency, female reproductive parameters and stock structure. These parameters are important for evidence-based management, and have been impossible to estimate for rare but wide-ranging shark and sawfish species.

Ongoing challenges are to optimise the identification of close-kin pairs, and to scope the potential of emerging genetic tools. It also remains to develop abundance and survival rate estimates for two shark species, and examples of how the outputs can provide evidence for the recovery of threatened and endangered species.

Speartooth Shark pup from the Adelaide River, NT.
Image: Charlotte Klempin, Charles Darwin University

Conducting sawfish research in the South Alligator River estuary, NT. Image: Charlotte Klempin

Supporting the IUCN Red List

ABOVE: **A juvenile Largetooth Sawfish. The sawfishes were arguably the most threatened family of marine fishes globally, with all five species globally Critically Endangered or Endangered.** Image: Peter Kyne

The International Union for Conservation of Nature (IUCN) Shark Specialist Group (SSG) pictures a world in which sharks and rays are valued and managed for sustainability.

Its members conduct IUCN Red List assessments, contribute to conservation strategies and policies, identify research needs, and communicate to a range of audiences. In January 2014, the SSG published the first systematic, global assessment of shark status and conservation (including extinction-risk across 1041 species) to help guide responses to the issue of shark declines.

Several NERP Marine Biodiversity Hub scientists participated in the SSG, including as the Co-Chair of Taxonomy and the Regional Vice-Chair for Australia and Oceania, thereby continuing more than a decade of involvement in the extinction risk study. Hub members also contributed to the global conservation strategy for sawfishes.

Approach

The IUCN Red List of Threatened Species Categories and Criteria was applied to assess extinction risk. Thirteen workshops were held worldwide (over the full period of the study) with the first in Queensland in 2003. Many Red List assessments for sharks and rays were authored or co-authored, and contributions were made to a global conservation strategy for sawfishes.

Key findings

The study found that, globally, 17.4% of all chondrichthyans were threatened with extinction and 46.8% were Data Deficient (insufficient information available to accurately assess status). Taking into account the possible status of Data Deficient species, 23.9% of all chondrichthyans were predicted to be threatened with extinction: higher than for birds, and comparable to mammals. In Australia, 15.6% of chondrichthyans were threatened with extinction and 23.3% were Data Deficient.

The sawfishes were arguably the most threatened family of marine fishes globally, with all five species globally Critically Endangered or Endangered. Northern Australia is a remaining population stronghold for the four species occurring in the Indo-Pacific.

New knowledge and opportunities

Many Australian chondrichthyan species are due for reassessment (species should be reassessed every 10 years). In collaboration with a James Cook University project (funded by the Fisheries Research and Development Corporation) to review the status of Australia's sharks, the IUCN Shark Specialist Group participated in an assessment workshop held in Townsville in February 2015 to reassess the status of all Australian sharks and rays for the IUCN Red List of Threatened Species. Australia's shark experts, including several Marine Biodiversity Hub researchers, undertook updated assessments for all 325 chondrichthyans (sharks, rays and chimaeras) occurring in Australian waters, with these to be published on the IUCN Red List later in 2015.

Involvement with the IUCN process 'provides an opportunity to complement species status assessments and recovery planning under Australia's *Environmental Protection and Biodiversity Conservation Act 1999* and state legislation.

The high level of data deficiency reinforces the need for more research that will reduce uncertainty to acceptable levels and promote a better understanding of the status and sustainability of chondrichthyans in Australia.

Outputs and outcomes

Additional scientific papers were published on topics including the global extinction risk and conservation of sawfishes, and the conservation status of North American, Central American and Caribbean chondrichthyans.

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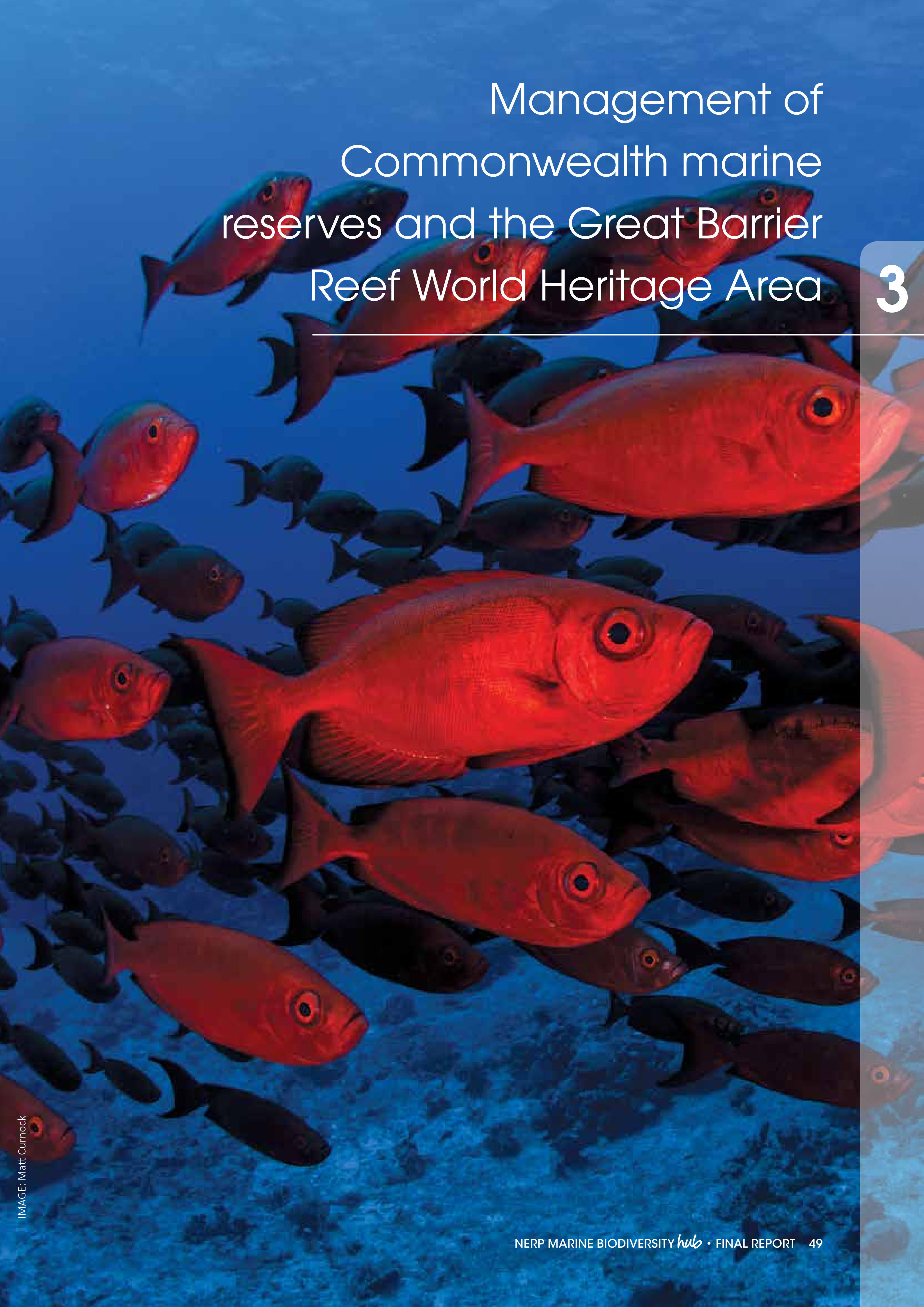


Management of Commonwealth marine reserves and the Great Barrier Reef World Heritage Area

3

IMAGE: Matt Curnock

The need

Commonwealth marine reserves are areas established under the *Environment Protection and Biodiversity Act 1999* (*EPBC Act*) to help conserve Australia's spectacular marine life.

The establishment of Commonwealth marine reserves in 2007 (South-east region) and 2012 (South-west, North-west, North and Temperate East regions and the Coral Sea) completed the Commonwealth waters component of the National Representative System of Marine Protected Areas (NRSMPA), and met the Government's commitment at the United Nations World Summit on Sustainable Development in 2002 to develop such a system by 2012.

The CMR network was designed to meet the needs of a comprehensive, adequate and representative system (CAR) that also minimised impacts on other marine users. Scientific input from the Commonwealth Environment Research Facility (CERF) Marine Biodiversity Hub included assembling all available data and predicting biodiversity distributions at medium to large scales (kms to thousands of kms) to meet the CAR objectives. While this scale of scientific data was appropriate for planning, it is of limited value for managing the CMR network. Management requires more detailed knowledge at finer scales so that any changes in the environment inside the CMR can be compared with changes in similar areas outside the CMR network.

In responding to the requirement for research to meet the needs of CMR network managers, Hub scientists have worked with the Department to:

- break down higher level policy objectives to scientifically measureable operational objectives;
- develop survey approaches to cost-effectively monitor (or provide a baseline to monitor against) fine-scale changes in biodiversity that are statistically representative of the broader marine reserve;
- conduct public surveys to determine how the public understands and values marine biodiversity and the CMR network;
- compare environmental conditions in areas closed to fishing compared with adjacent fished areas.

In the process of this research, Hub scientists have:

- improved the knowledge and description of the marine environment within selected CMRs;
- collated existing data to show the pressures facing the marine environment and their potential for cumulative impact (Section 1);
- conducted an extensive review of existing data for 54 CMRs (Section 1); and
- identified fish communities in all 14 reserves of the SECMR network.

Monitoring the Great Barrier Reef World Heritage Area

At the request of the Australian Government, Hub researchers led a collaborative research project to establish an integrated monitoring framework for the Great Barrier Reef World Heritage Area, including social and economic aspects. The framework was designed to contribute to the strategic assessment of the Great Barrier Reef under the *EPBC Act*, as well as to the *Long-Term Sustainability Plan for the World Heritage Area*.

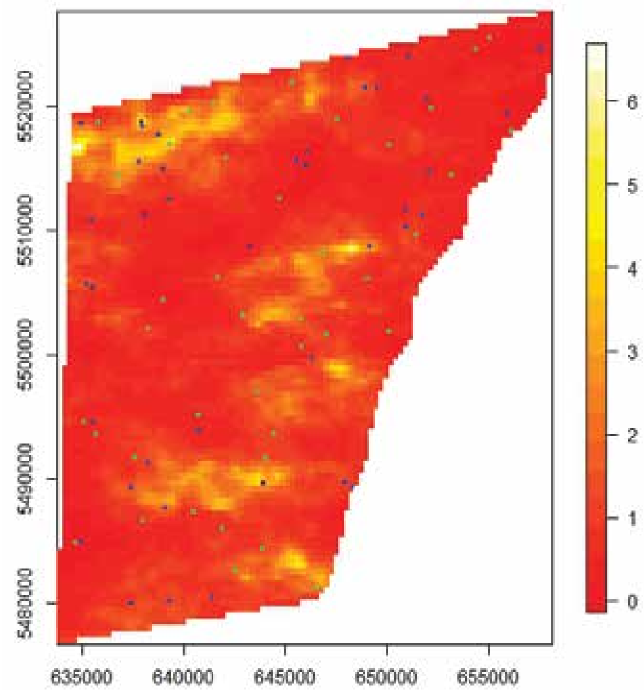
IMAGE: Reef Life Survey

Applying spatially balanced survey designs to monitor indicators in Commonwealth marine reserves

Australia's Commonwealth Marine Reserve (CMR) network covers 2.76 million km^2 of continental shelf, slope, and abyssal habitat.

The shelf provides a mosaic of shallow water habitats (to about 200 metres deep) that support a diversity of marine species and species assemblages, but little is known about the extent of these habitats or the status and trends of their associated assemblages. One way to address this important knowledge gap is to map the seafloor using multi-beam sonar (MBS) but in these water depths this would be a slow process.

A survey vessel dedicated to mapping 24 hours a day, every day of the year, would take 3.5–17.5 years to cover the 306,627 km^2 of CMR seafloor lying within the biologically diverse 40–200 m depth range. Even then, data would be available only for the seafloor habitats, not the resident species and assemblages. A more pragmatic approach is required to provide early and cost effective methods to gain insight about the extent of shelf habitats in CMRs and the status and trends of marine life.



ABOVE: **A hypothetical surface showing the typical patchiness of a benthic biodiversity indicator in the South-east CMR network, together with the features of 40 Simple Random Samples (blue dots) and 40 spatially balanced GRTS samples (green dots). The clumping of the SRS samples is clearly evident, and in this instance the SRS samples fail to identify the biodiversity hotspot in the bottom right of the sample frame. Both designs capture the true mean value of the indicator but the confidence interval of the SRS estimator is 20% larger than that of the GRTS estimator because the variance of the indicator is higher.** Image: CSIRO

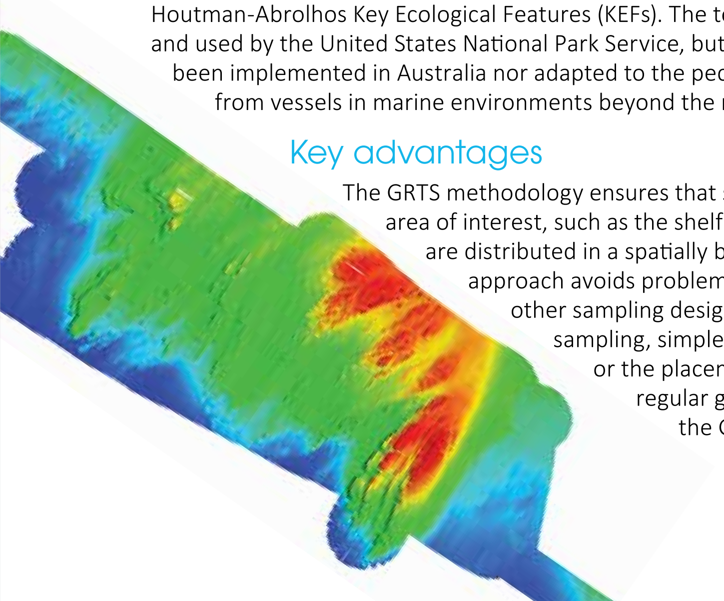
BELOW LEFT: **The GRTS design was used in surveys of the Tasman Fracture CMR to target reef habitat.** Image: CSIRO/IMAS

This project successfully implemented a new sampling approach that enables managers to acquire accurate baseline measurement of environmental assets in the CMR network. Trends in these assets can also be collected in a cost-effective manner during the prolonged period required to complete mapping. Establishing the baseline status of the CMR network at an early stage, and tracking trends in key indicators, are essential for management agencies to get timely information on the performance of the CMR network.

Approach

The alternative approach to continuous MBS acquisition termed a GRTS (Generalised Random Tessellation Stratified) design works by collecting samples at small scales across broad areas. Sampling inference methods are then used to draw conclusions about the entire region of interest (such as a zone or reserve). This approach can complement continuous MBS acquisition and allow monitoring of status and trends to start during the long lead-in time required to acquire continuous MBS data.

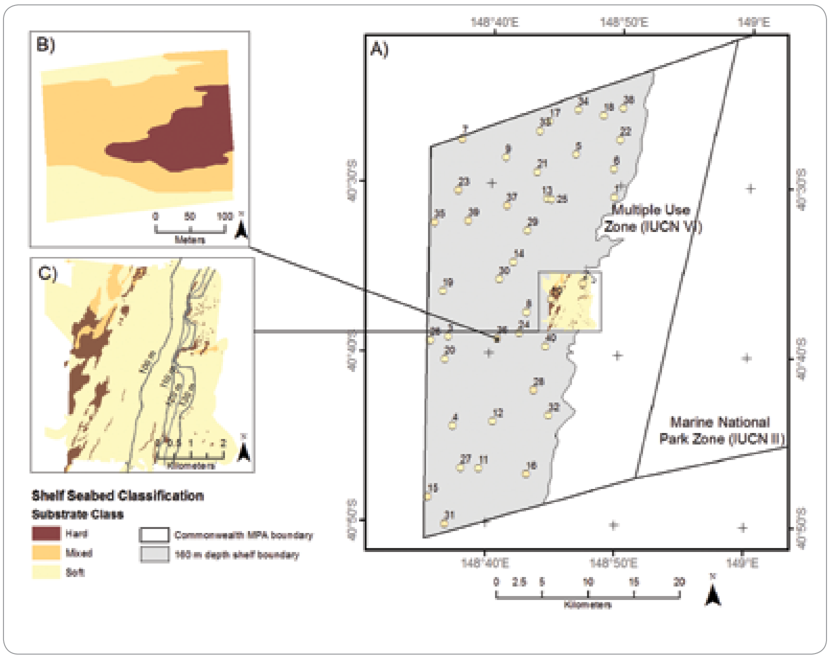
Theme 1 of the Marine Biodiversity Hub trialled the GRTS approach in the Flinders CMR, and subsequently employed it in the Geographe CMR and Houtman-Abrolhos Key Ecological Features (KEFs). The technique is endorsed and used by the United States National Park Service, but has not previously been implemented in Australia nor adapted to the peculiarities of sampling from vessels in marine environments beyond the reach of divers.



Key advantages

The GRTS methodology ensures that sample sites in an area of interest, such as the shelf habitats of a CMR, are distributed in a spatially balanced way. This approach avoids problems experienced with other sampling designs such as judgemental sampling, simple random sampling, or the placement of samples on a regular grid. The flexibility of the GRTS approach also means that the survey design can accommodate unexpected loss of sampling effort due to poor weather, equipment breakdowns, or the vagaries of the funding cycles, without comprising statistical validity.

Judgemental samples cannot be used to infer the status of regions that are not sampled. Simple random samples are undesirable because they tend to clump in space (see figure above). On average they are less likely than spatially balanced samples to detect features of



LEFT: **(A) Multibeam sonar habitat mapping and sample locations (1–40) of the GRTS design drop camera survey of shelf habitats of the Multiple Use Zone of the Flinders CMR showing the cluster of mixed reef sample points discovered in the north-western corner of the reserve. MBS mapping of the drop camera locations (B), and of a continuous patch of seabed (C) shows the typical patchiness of the reef habitat.** Image: GA/CSIRO/IMAS

interest, such as regions of high benthic biodiversity in the CMR network associated with distinct reef features that can be tens to thousands of metres apart. The clumping also acts to inflate estimates of indicator variance, (an essential factor in determining evidence for a trend). And while regular grid sampling can allow the mean value of an indicator to be assessed, it does not allow the variance of the indicator to be estimated.

New knowledge and opportunities

By applying spatially balanced designs, Marine Biodiversity Hub project teams discovered what appears to be a cluster of mixed reef habitats in the north-western corner of the Flinders CMR reserve (see figure at left), and seagrass beds and reefs in the Geographe CMR that are much more extensive than previously thought (see stories on pages 54 and 57. Furthermore, the GRTS design allows survey teams to preferentially sample areas of particular interest if the location of these areas is known in advance. This facility was put to good use in the survey within the Tasman Fracture CMR to target reef habitats of rock lobster. It ensured a good sample size to test the effect of the exclusion of fishing within part of the CMR on the size-frequency distribution of rock lobster, and ensured that the data collected are representative of the CMR as a whole.

Outputs and outcomes

Spatially balanced survey designs have been successfully trialled at several CMRs and KEFs, facilitating design and model-based inference of the extent and status of benthic habitats that would have not been identified using judgmental, simple random or regular survey designs.

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LEFT AND ABOVE: **The GRTS design allows survey teams to preferentially sample areas of interest if the location is known in advance. This facility was used in surveys of the Flinders CMR, and to discover seagrass beds and reefs in the Geographe CMR.** Images: CSIRO (left) and Curtin University

Valuing the South-east Commonwealth Marine Reserves Network

Marine reserve networks are designed to protect biodiversity and maintain the ecological integrity of marine ecosystems, however trade-offs are involved in their design and priorities need to be identified for effective management.

The costs and benefits of different designs, and priorities for stakeholders that have direct links to the ocean are relatively easy to quantify. Less so are the costs and benefits on the general public, who may hold 'existence values' for assets protected by these networks.

Identifying and quantifying these existence values may highlight a public desire for management, and provide management guidance. This research will provide information to managers about public attitudes, understanding and effectiveness of communication in relation to marine reserve networks such as the South-east Commonwealth Marine Reserves (SECMR) Network. It will also develop an understanding of how coastal and marine decision makers understand and apply the economic valuation of environmental services.

Approach

Decision makers and members of the public are being surveyed. In the latter case, large scale representative samples of the relevant population (from south-eastern Australia) have been surveyed. The surveys include many attitudinal questions about the respondents' knowledge and perceptions of the SECMR (such as threats, purpose, and level of protection). These are complemented by valuation questions, using the choice experiment format. Respondents are asked to choose between hypothetical management investments intended to protect different assets to differing degrees. This process reveals which aspects of the SECMR the respondents' value most. The effect of varying the form of presentation of information about the reserve system (including videos and expert opinion) on values is also explored.

Although a significant amount of work on identifying public values for environmental assets can potentially be used to support management, it is not clear to what extent such information is viewed as valuable by decision makers. To address this issue, in 2013, an Australia-wide survey of decision makers involved coastal zone and marine management used the Analytic Hierarchy Process to elicit the importance of different types of information used in decision making.

ABOVE: **A seastar among deepwater corals at 1115 m water depth in the Huon CMR, part of the South-east Commonwealth Marine Reserves Network.** Image: CSIRO

LEFT: **A lobster forages on deep reef in the Huon CMR.** Image: IMAS

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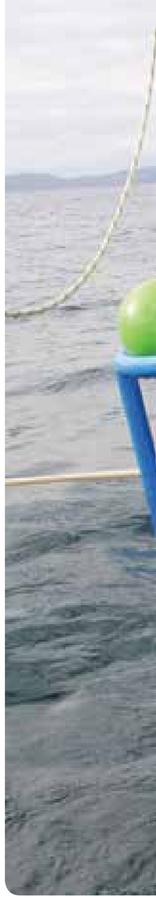
Key findings

Full public surveys are ongoing, but the results of the pilot surveys are informative. In the choice experiment, respondents revealed positive values for protection, but only if they had prior knowledge of the ecosystem attributes. This early finding suggests that the preferences revealed are not 'constructed' during the survey, but may in fact reflect robust, pre-existing values. Public education may extend those values to a broader section of the community. Ongoing work will reveal the extent to which these values are affected by the way information is provided in the survey.

The survey of decision makers found that biophysical criteria were used in preference to economic values (such as existence values derived from surveys) in decision making. This partially reflected the academic background of most decision makers, with relatively few having formal economics training. The survey also found that, in most cases, appropriate economic valuation information was not available for use, and decision-making processes had developed in the absence of such information. Increased availability of economic valuation data may increase its use in decision making.

Outputs and outcomes

This research is part of a large program of valuation surveys that will provide information on the values held by community members for several Australian marine ecosystems. It is building knowledge about the perceptions of the community towards marine reserve and marine assets, in terms of threats and current status. It also identifies the values held for assets protected within marine reserves, and the way that the public is prepared to trade-off different assets.



Surveys of Commonwealth marine reserves: Flinders

The Flinders Commonwealth Marine Reserve (CMR) east of Tasmania's Cape Barren Island stretches some 600 kilometres and covers an area of 27,000 km^2.

Temperate reef systems in the CMR support many mobile and commercially-important species, but little has been known about biological communities beyond depths accessible to divers (below 25 m). This project trialled cost-effective survey techniques in the Flinders CMR, based on a novel application of a Generalised Random-Tessellation Stratified (GRTS) design (see story on page 51). It quantified and documented habitats and communities, mapped an important canyon head feature, and launched a new, deep water Baited Remote Underwater Video (BRUV) system. The survey approach will facilitate biodiversity baseline inventories, monitoring, and performance comparisons across Australia's CMR network.

Approach

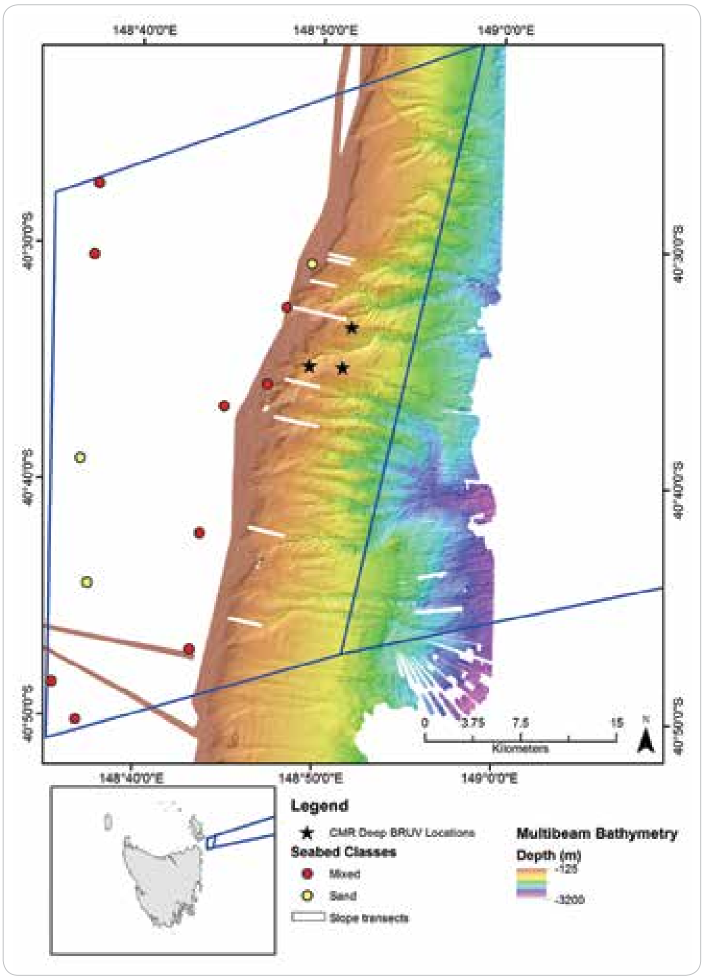
A flexible, two-phase survey design was implemented for the area of the Flinders CMR confined to the shelf. Phase one of the GRTS survey used a drop camera to characterise the seabed habitat at 40 sites. In phase two, further habitat and biological samples were obtained from 12 of these sites using high-resolution multibeam sonar, towed stereo video and shallow BRUV systems. Locations identified (during Phase 1) as low-profile reef supporting rich fish and invertebrate communities were preferentially sampled in this process.

As a comparison to the GRTS-based approach, an area of approximately 30 km^2 – within which shelf-incising canyon heads were known to be located – was continuously mapped using a high-resolution multibeam sonar. This mapping confirmed the presence of several low-profile reefs, some of which may be relict coastline features. Autonomous underwater vehicles were used to obtain further samples of habitats, fish and invertebrate communities on these reefs without the need for invasive sampling. In a first for Australian researchers, the survey team also deployed and retrieved three deep BRUV systems in water depths exceeding 500 m on the slope of the Flinders continental shelf.

Key findings

This project showed that cost-effective, quantitative baseline estimates of demersal habitat types and associated invertebrate communities can be developed for the shelf and upper slope regions of temperate CMRs (in this case Flinders CMR). Demersal fish communities in shelf regions can also be inventoried and characterised.

Diverse reef systems revealed during the survey include steep, canyon-head structures with underwater cliffs, flat sedimentary rocks, and sandstone and mudstone stacks with ledges sheltering invertebrates such as commercially important rock lobsters and fishes. Different seabed features such as low profile, often sand-inundated reefs, and step features and canyon heads, had quite different assemblages, showing that further sampling is needed to fully understand the diversity of the Flinders CMR shelf. Ultimately, complete multibeam mapping with representative biological sampling is needed to fully inventory the extent and types of habitat and the cover of key benthic species, but the GRTS approach provides a statistically valid interim baseline to improve knowledge and understanding of conservation values in the Flinders CMR.



RIGHT: **Multibeam mapping completed at depth in the Flinders CMR. Stars mark the sites of BRUV drops and coloured dots indicate predominant substrate type: sand or mixed (reef sand).** Image: CSIRO/IMAS/GA

ABOVE LEFT: **Photographic inventories of deep-water fish communities at 500 m depth were made for the first time in the Flinders CMR using Deep BRUVs: baited, instrumented, camera systems deployed on the seabed. Electronic controls initiate and synchronise the cameras, lights and bait delivery, enabling images to be collected for extended periods (weeks to months). Sensors measure environmental conditions.**

ABOVE CENTRE: **Sponges and bryozoans growing on low-profile reef on the shelf of the Flinders CMR. This image was taken with the CSIRO towed stereo camera system at 38 m depth.**

ABOVE RIGHT: **Striped Trumpeter in the Flinders CMR.** Images: IMAS

New knowledge and opportunities

The survey approach used in this project was designed to meet the statistical requirements for establishing a long-term monitoring baseline. It aims to do this cost-effectively by maximising the information obtainable from a time-limited survey, and providing a statistically coherent process for incorporating information collected in future surveys. Seabed features and associated fauna are sampled in a way that enables their abundance throughout the CMR to be quantified, features of interest to be targeted, and biodiversity estimates improved. This represents a significant advance on typical deep-water surveys.

A previously unknown cluster of mixed reef habitat was identified in the north-western corner of the Flinders CMR shelf (now a candidate for subsequent continuous multibeam sonar). It has provided a basis for identifying candidate indicator species that can be monitored for evidence of change.

The survey provided the first in-field experience with deep BRUVs and identified ways to improve equipment design and data analysis. With future hardware development, deep BRUVs have good potential for monitoring deep seabed ecosystems, and can be cost-effective because they can be deployed and retrieved by passing fishing vessels.

Outputs and outcomes

This project trialled a combination of techniques for long-term monitoring that are cost-effective, non-extractive, flexible, have a high power for extrapolation, and are transportable to the deep ocean (a large portion of CMRs). The techniques were used to produce quantitative estimates and high-resolution maps of reef systems and associated diversity across the Flinders shelf.

Quantitative baseline estimates and a comprehensive inventory of potential targets for sustained CMR monitoring strategy were demonstrated, (contingent on CMR operational objectives), providing valuable learning experiences that will improve the cost-effectiveness of future surveys.

Standardised statistical survey design and methods are essential for establishing trends in key indicators within a CMR, and for cross-comparison between CMRs. These comparisons will assist in network management and review, and can be designed to be adaptable to changing survey capacity.

The spatially balanced design approach developed for this CMR has subsequently been used for surveys in the Oceanic Shoals, Geographe and Tasman Fracture CMRs.

A collaborative approach that pooled the expertise and capacity of diverse research partners was pivotal to the successful application of new and existing sampling techniques within a novel statistical design, and emphasised the value of collaboration.

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Southern Rock Lobster thrive in Tasman Fracture CMR

The Tasman Fracture Commonwealth Marine Reserve (CMR) is the southernmost CMR of the continental Australian CMR network. It has been established for more than seven years, and protects previously-fished shelf reef habitats in a 'no-take' Marine National Park Zone, one of few such zones on the shelf within the South-east CMR network. This project evaluated the effects of this protection on target species (particularly for Southern Rock Lobster) and their ecosystem, and contrasted the changes with adjacent habitats that remained open to fishing.

Multibeam sonar mapping found most reef habitat in the north-west of the protected zone, continuing as coastal reef systems in adjacent state waters. The reefs typically extended to about 100 m in depth, except for an isolated patch reef in the eastern sector that extended to 140 m depth and forms a unique feature of this CMR, rising up to 20 m above the seabed.

An intensive rock lobster potting survey on reef systems in and adjacent to the CMR examined lobster abundances and size structure in fished and protected locations. Initial findings indicate that overall abundances in the CMR protected zone are approximately 30% of nearby fished habitats (as the CMR contains significantly more deep reef than nearby fished locations, and less of the shallower habitat that lobsters prefer).

When depth-related differences in abundance were accounted for, however, the size structure reflected a strong effect of protection, with markedly larger male and female lobsters in the CMR. Model-based analysis is under way to further examine these patterns.

An Autonomous Underwater Vehicle survey took a photographic inventory of benthic habitats, to help calibrate multibeam sonar estimates, and describe the dominant benthic biota. In March, a baited underwater video provided an initial inventory and size frequency of fish fauna to identify whether target species such as Stripey Trumpeter and Jackass Morwong have benefited from the no-take protection.

When completed, this project will have provided an inventory of the shelf reef habitat and associated benthic fauna of the 'no-take' zone of the Tasman Fracture CMR, an understanding of the benefits that no-take protection may offer exploited populations, an insight into the ecological processes that structure deep reef populations in the CMR, and a greater understanding of cross-shelf reefs.

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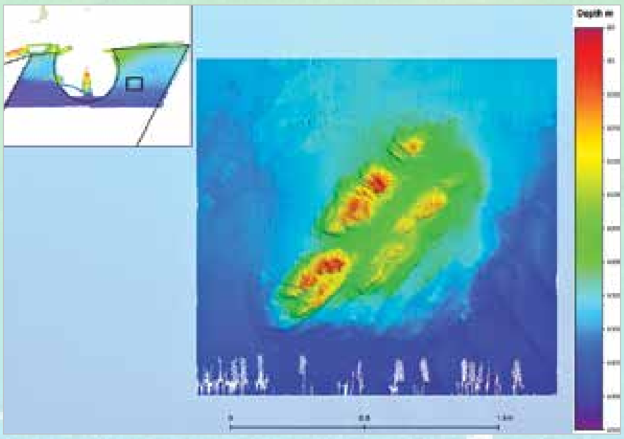

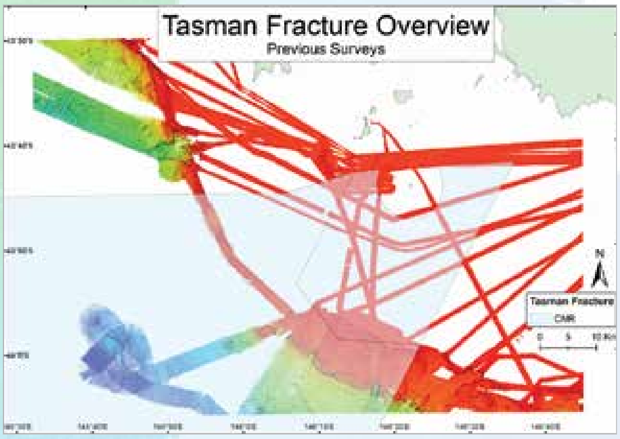

TOP: **An intensive rock lobster potting survey on reef systems in and adjacent to the CMR examined lobster abundances and size structure in fished and protected locations.** Image: IMOS/IMAS

ABOVE LEFT: **The isolated patch reef that provides the most defining feature of the eastern sector of the no-take zone in the Tasman Fracture CMR. It is approximately 1 km in length and 300 m wide, and ranges from a depth of 95 m to 130 m.** Image: IMAS/CSIRO

ABOVE RIGHT: **An overview of knowledge of the Tasman Fracture CMR seabed features on the shelf and slope prior to the detailed NERP Hub survey of shelf reef habitats. The CMR is indicated by blue shading and the 'no-take' zone is delineated by a red-line in the eastern segment of the shelf.** Image: IMAS/CSIRO

Surveys of Commonwealth marine reserves: Geographe

The Geographe Commonwealth Marine Reserve (CMR) lies within and adjacent to Geographe Bay south of Perth, Western Australia, and has a depth range of 15–70 m.

It is an area of high benthic productivity and high biodiversity that provides habitat for threatened and migratory seabirds, the humpback whale and blue whale, and the Western rock lobster. More information is needed in order to establish a monitoring program for this reserve, which adjoins the Ngari Capes Marine Park (in state-managed waters). This project designed a statistically robust baseline survey of the Geographe CMR to meet the research and monitoring needs of Parks Australia.

Approach

Existing information was collated on the distribution and characteristics of key habitat types (seagrasses, corals, rocky reefs and soft sediments) and associated benthic invertebrate and benthic vertebrate communities in the Geographe CMR. A statistically robust survey was designed to meet survey objectives defined with input from Parks Australia, building on and trialling survey methodologies developed for the Flinders CMR (see story on page 54). The survey was implemented during the period December 2014 to March 2015, and the data analysis and final report will be completed by the end of June 2015.

The survey consisted of 150 Baited Remote Underwater Video (BRUV) drops across the CMR. The sampling sites were selected using the Generalised Random Tessellated Stratification survey design (see story on page 51). Additional habitat information was obtained by placing rear facing cameras on the BRUV units. The field crew were also able to deploy 50 BRUVs at known reef and seagrass features, thereby augmenting existing information on the fish communities on these features. Autonomous Underwater Video transects will be completed in late March 2015.

Key findings

Preliminary analyses indicate that Geographe appears to contain one of the largest continuous seagrass beds recorded. Fish assemblages differ by depth and habitat (seagrass, reef, sand). The complete project findings will be available in June 2015.

New knowledge and opportunities

The survey approach proved a cost-effective way to provide a CMR baseline and a consistent monitoring approach that will support future comparisons between CMRs and regions. The GRTS design was supplemented with targeted reef monitoring based on expert knowledge.

Outputs and outcomes

Existing information has been collated and documented for key habitat types and associated communities in Geographe CMR. Anticipated outcomes include a statistically robust baseline of habitat extent – including a characterisation of habitat types and associated benthic communities – that will provide a basis for subsequent trend analysis to meet Parks Australia management objectives.

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TOP: **A Prickly Leatherjacket (*Chaetodermis penicilligera*) camouflaged among macroalgal habitat at the Geographe CMR is photographed by a stereo baited remote camera system.**

ABOVE LEFT: **An Eagle Ray (*Myliobatis tenuicaudatus*) and two Pink Snapper (*Pagrus auratus*) on a mixture of macroalgal and sand habitat.**

CENTRE LEFT: **A Western Blue Grouper (*Archerodus gouldii*) swims past smaller reef fish feeding on the bait bag of a stereo-baited remote video system.**

BOTTOM LEFT: **A large Smooth Stingray (*Dasyatis brevicaudata*) swoops over the bait bag on a macroalgae substrate.** Images: Curtin University

Sand and granite reef communities revealed at Freycinet CMR

Parts of the Freycinet Commonwealth Marine Reserve (CMR) east of Tasmania were opportunistically mapped by the Marine Biodiversity Hub during transit voyages between Hobart and the Flinders CMR, a focus of Hub research. The transit mapping, plus additional, targeted transects, revealed relict coastline reefs in 80–100 m depths extending north of Bicheno. The reefs appear relatively continuous in the CMR, and provide important habitat for Stripey Trumpeter, an important species for commercial and recreational fishers.

Further mapping detected reef features inshore of the relict coastline: complex granite reef systems supporting more substantial fish and invertebrate assemblages. Most notable was a 200 m long granite reef 7 km south-east of Bicheno that rose sharply from 80 m to 60 m. Benthic habitats and biodiversity have been photographed in repeated surveys with an autonomous underwater vehicle (AUV).

(AUV surveys were begun at Freycinet CMR during the Commonwealth Environment Research Facility Marine Biodiversity Hub; later surveys have been supported by the Integrated Marine Observing System, the Institute for Marine and Antarctic Studies and the Department of the Environment.)

Preliminary examination of the AUV imagery indicates that the relict reef systems are generally very low profile and partially sand-inundated, with a sparse coverage of sponges and similar invertebrates, few benthic fish, and with distinct brittlestar aggregations at the reef to sand interface. In stark contrast, the granite reef has an extensive and complex sponge, bryozoan and ascidian fauna and an abundant fish assemblage, dominated by Butterfly Perch.

Further work on the AUV imagery would provide a greater understanding of bioregional patterns, and year-to-year variability in biological indicators of change. The acquired imagery and metadata is available on the Australian Ocean Data Network.

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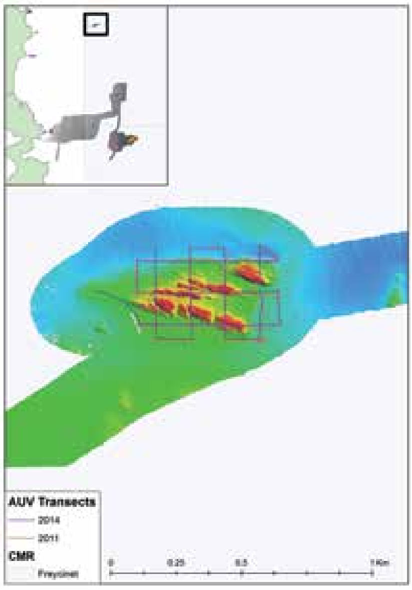

TOP: **An isolated granite reef mapped 7 km to the south-east of Bicheno at the Freycinet CMR. Tracks show the location of AUV surveys undertaken in 2011 and 2014 to provide an understanding of the biota and its temporal variability in high-profile deep reef systems of the CMR network.** Image: GA/IMAS

ABOVE: **The AUV *Sirius* being deployed in the Flinders CMR from the Australian Maritime College Vessel *Bluefin*, on charter to the NERP Marine Biodiversity Hub.** Image: IMAS

UPPER RIGHT: **An AUV-derived image of the benthos at the interface between sediments and relict reef systems on the shelf in the Freycinet CMR. Features include bare sand to the right, an interface marked by brittlestars, sponges, ascidians and drift algae, and the sand inundated invertebrate turf matrix typical of the relict reef itself.** Image: IMOS/IMAS

LOWER RIGHT: **An AUV-derived image from the granite bommie survey shows large sponges (massive and finger morphotypes), sea fans, and butterfly perch.** Image: IMOS/IMAS

Surveys of Commonwealth marine reserves: Coral Sea

Australia'a Coral Sea Commonwealth Marine Reserve (CMR) covers an area of 989,842 km^2 and is one of the largest marine protected areas in the world.

Key Ecological Features identified for the Coral Sea include the Tasmantid seamount chain and the reefs, cays and herbivorous fishes of the Queensland and Marion plateaus. Despite the ecological value of emergent reefs in the Coral Sea, integrated surveys to characterise the distribution of reef communities have been lacking. This project analysed data from surveys covering most reefs in the Coral Sea CMR, helping to improve the scientific information base for reserve management.

The results of recent fish, invertebrate and coral surveys by trained volunteer divers associated with Reef Life Survey (see story on page 65) at the majority of Coral Sea reef systems were analysed in this project. These data provide an ecological baseline of the state of shallow-reef biodiversity across the Coral Sea.

Approach

Data generated by volunteer Reef Life Survey divers were analysed following surveys of densities of fishes, invertebrates and macroalgae at 17 of 19 major reef systems across the Coral Sea. Dive teams surveyed 160 sites, primarily during May to July 2013. Of 160 sites analysed, 35 were in the former Coringa-Herald and Lihou Reef national nature reserves (declared in 1982) while all others were on reefs open to commercial and recreational fishing, albeit now included in the larger Coral Sea CMR.

Key findings

Coral Sea reef communities were found to be unique in Australian territory. They had different dominant fish and invertebrate species to those commonly observed on shallow reefs along the Great Barrier Reef (GBR), and a high similarity to reefs off oceanic Pacific islands over 1000 km distant, such as Tonga.

Fish communities differed between northern (north of Marion Reef) and southern reefs. Areas closed to fishing since 1982 (the Coringa-Herald and Lihou reef systems) supported higher fish biomass than comparable sites. Abundance patterns were driven largely by planktivorous and benthos-associated damselfishes, schooling wrasses, and small-bodied surgeonfishes, while biomass patterns were typically driven by the few large-bodied individuals, such as sharks, groupers, coral trout and large grazers.

RIGHT, FROM TOP: **Bird Island Reef in the Coral Sea; The olive sea snake (*Aipysurus laevis*) was extremely common on reefs in the southern Coral Sea, a global hotspot for seasnake diversity; Coral Sea reefs are inhabited by many species that are common among central Pacific Islands, but rare on the Great Barrier Reef, such as this ocellate damselfish (*Pomacentrus vaiuli*) at Cato Reef.**

BELOW: **Wreck Reef in the Coral Sea.** Images: Reef Life Survey

Coral Sea reefs possess high densities of reef sharks and sea snakes, and are a global hotspot for these groups. With declining numbers of sea snakes on the GBR and off north-western Australia, the southern Coral Sea is a remnant stronghold for sea snake species. Sea snakes were ubiquitous and abundant on all reefs from Marion Reef southwards, but were not observed on more northern reefs. Higher numbers of reef sharks were sighted by divers in this survey than present at most locations worldwide. The survey also provided a first indication of sea turtle occurrence on many of the Coral Sea reefs.

Coral assemblages of most reefs were dominated by encrusting corals, with some exceptions. Coral cover is relatively high on southern reefs such as Cato and Wreck Reefs (approximately 40%), where fragile branching corals are common, but tends to be much lower on central and northern reefs, probably due to frequent cyclone disturbance.

New knowledge and opportunities

Reef Life Survey provides a scientifically validated and cost-effective option for consistent, long-term biodiversity monitoring of shallow marine biota, including for offshore locations that are expensive to visit, such as the Coral Sea.

The consistent, wide-ranging data collected by the surveys is establishing a global context that will enable trends over time in areas such as the Coral Sea to be compared on a regional, national and international scale.

Outputs and outcomes

The Coral Sea CMR provides a reference yardstick for assessing changes in similar wave-exposed coral reef environments with greater human-related stresses, including across the wider oceanic Pacific region. Ongoing monitoring of the same sites and reefs using comparable methodology will contribute to long-term conservation management of the Coral Sea CMR.

Data from the Coral Sea survey are being made available through the Australian Ocean Data Network portal: data for fishes are partially available, and data for invertebrates will become available later in 2015.

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ABOVE: **A Queensland Groper (*Epinephelus lanceolatus*) at Bird Reef in the Coral Sea.**

LEFT: **A Reef Life Survey diver counts invertebrates at Holmes Reef in the Coral Sea.** Images: Reef Life Survey

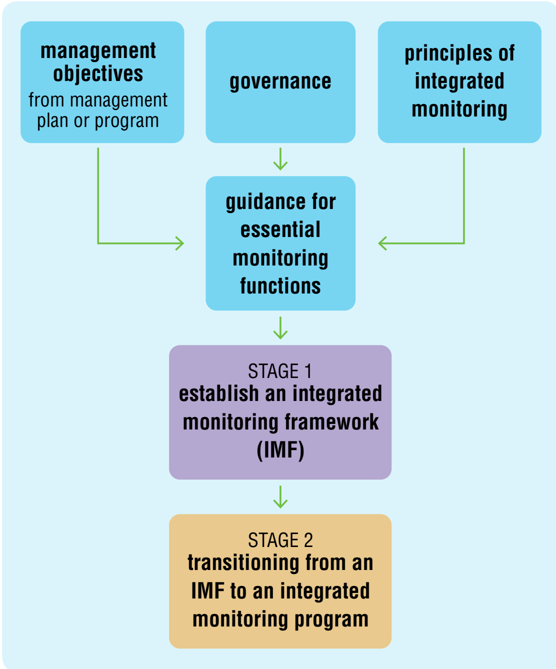
Shaping integrated monitoring for the Great Barrier Reef World Heritage Area

The Great Barrier Reef (GBR) was inscribed on the World Heritage list in 1981 in recognition of its outstanding universal value.

In addition to its biophysical values, the GBR Region contains important elements of cultural and indigenous heritage, and supports many community and economic benefits such as fishing and tourism. As highlighted in the *GBR Outlook Report 2014*, cumulative pressures are diminishing the resilience of GBR ecosystems. Living coral is declining, with the average coral cover falling by half between 1985 and 2012. While the effects of cyclones, crown-of-thorns starfish and coral bleaching are the main causes of coral mortality, most long-term declines have occurred in central and southern regions, where human pressures are the most intense.

Monitoring in the GBR Region typically has responded to emerging issues (such as crown-of-thorns starfish), long-term trends, or legislative requirements, rather than cumulative impacts or overall management needs. Furthermore, social and economic monitoring has not been a high priority. This project has built the framework for a standardised and integrated ecological, social and economic monitoring program for the GBR World Heritage Area that will be used to address these earlier shortcomings.

GUIDANCE TO ESTABLISH AN INTEGRATED MONITORING FRAMEWORK



ABOVE: **An overview of the guidance required to establish an integrated monitoring framework (what needs to be considered).**

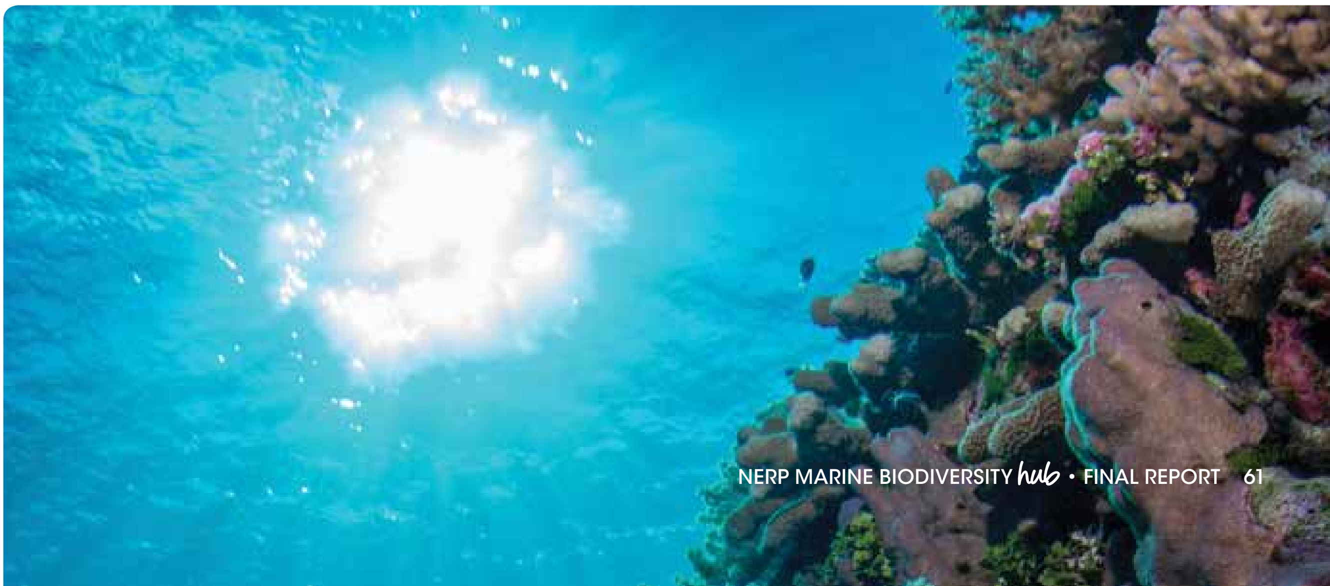
Approach

An approach that learns from measurable outcomes was taken to establish an integrated monitoring framework to support adaptive management. The GBR Marine Park Authority reviewed information needs for managing the GBR World Heritage Area, and the Australian Institute of Marine Science (AIMS) reviewed existing monitoring programs. Other collaborators included the NERP Marine Biodiversity Hub, the NERP Environmental Decisions Hub, the NERP Tropical Ecosystems Hub and the Queensland Department of Environment and Heritage Protection.

The integrated monitoring framework was established using practical guidance developed specifically for this project. The guidance was developed using knowledge and advice from a broad range of experts in the fields of policy development, natural resource management, science and data management.

The framework described in this report is based on the seven essential monitoring steps identified by the United States National Park Services. Conceptual models are central to capturing and communicating interactions between ecosystems, society and the economy to furnish all stakeholders a similar understanding of how the system functions.

BELOW: **Living coral is declining in Great Barrier Reef ecosystems.** Image: Reef Life Survey



Tourism is one of many community benefits bestowed by the GBR region. Image: Matt Curnock

Key findings

The integrated monitoring framework established by this project provides the foundation for developing an integrated program for the GBR World Heritage Area. The program would monitor, evaluate and report on the condition of and trends in values underpinning relevant matters of national environmental significance and the associated drivers and pressures. This includes Outstanding Universal Value recognised under the World Heritage listing, as well as benefits to the community.

Governance is critical to the leadership and coordination required for integrated monitoring, to articulate clear responsibilities for prioritisation, and to effective implementation. Governance arrangements for the Reef Water Quality Protection Plan 2013 may provide a useful model for guiding the development of the governance arrangements necessary to coordinate a monitoring program for the World Heritage Area.

Fifty-two high-priority values, processes, pressures and drivers (reduced from hundreds) have been identified for monitoring. Further refinement is needed to reduce the number of priorities and to improve the specificity of the priorities and their objectives.

Sixty-five existing monitoring programs were candidates for inclusion in an integrated monitoring program. This existing network, while relatively extensive, is insufficient to monitor the identified priorities.

Multi-stakeholder workshops identified the following monitoring programs as fundamental building blocks: the AIMS Long Term Monitoring Program, the Eye on the Reef monitoring program, the Integrated Marine Observing System, the Paddock to Reef Monitoring Program, commercial fisheries monitoring, seagrass monitoring, the Social and Economic Long Term Monitoring Program and threatened species monitoring.

Integrated monitoring for the World Heritage Area will require broader use of conceptual models, development and promotion of standard monitoring protocols, and improved coordination and collaboration between end-users and existing data management systems. Existing monitoring programs will need to better serve managers, and an overarching data analysis and reporting group or unit will be needed.

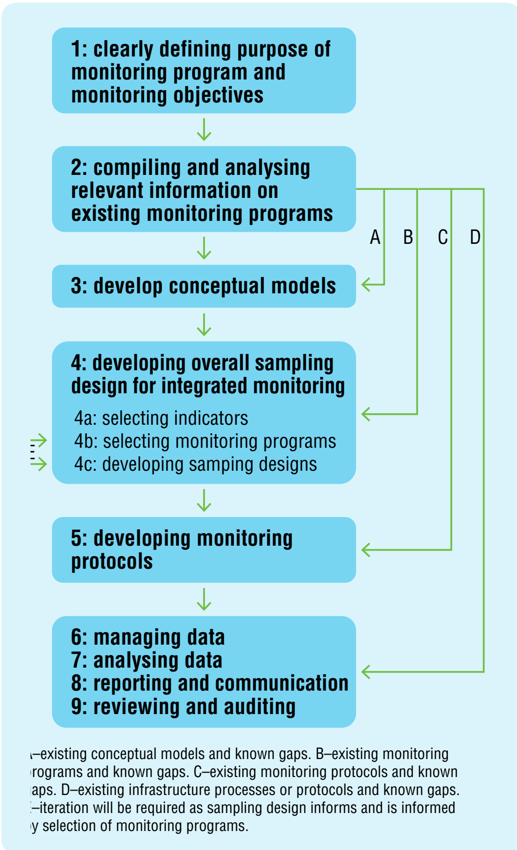
New knowledge and opportunities

The integrated monitoring framework provides the basis for effective monitoring of the World Heritage Area. It articulates monitoring priorities, provides the first assessment of the capacity of existing monitoring programs to address these priorities, and provides direction for integrating long-term monitoring with short-term and compliance monitoring programs. The framework can be used more broadly in Australia. For example, it built on knowledge developed for monitoring marine ecosystem health (the monitoring blueprint) and will contribute to monitoring for future strategic assessments.

Outputs and outcomes

Guidance has been provided for establishing an integrated monitoring framework to support adaptive management of the GBR World Heritage Area, and an integrated monitoring framework has been established. Information needs for management, and existing monitoring programs, have been reviewed during this process.

APPLYING THE GUIDANCE FOR ESSENTIAL MONITORING FUNCTIONS



ABOVE: **Essential monitoring functions to be considered in developing an integrated monitoring framework.**

The framework contributed to a strategic assessment of the World Heritage Area and is guiding the development of a reef-wide integrated monitoring and reporting program to review the success of the *Reef 2050 Long-Term Sustainability Plan* (draft released for public comment in September 2014). It will build upon and coordinate existing monitoring and reporting activities and will be linked to the outcomes and targets identified in the Plan.

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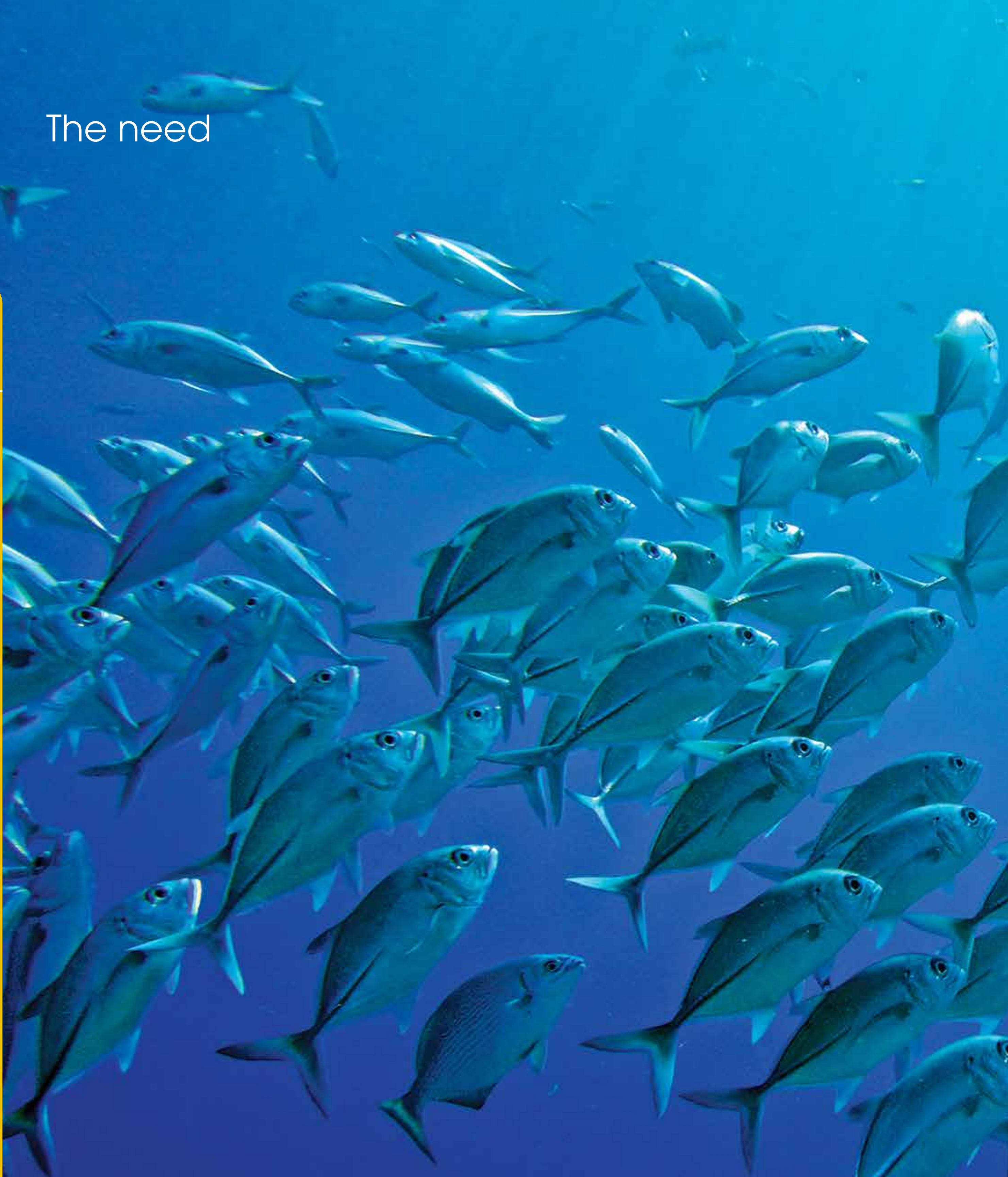
IMAGE: Reef Life Survey

International extension 4

The need



The Australian Government has regional partnerships and international responsibilities that can benefit from scientific exchange.

These include marine bioregional planning, establishment of the Commonwealth Marine Reserve network, and fisheries management. Communicating these developments assists countries in the region and beyond, and profiles Australia's capabilities.

While international scientific research and extension are not directly supported by the NERP Program, the benefits are significant. This section provides examples of how Marine Biodiversity Hub research has been showcased, thereby supporting the Australian Government's broader international agendas.

Reef Life Survey global analysis of marine protected areas

Reef Life Survey (RLS) conducts long-term monitoring of coastal habitats which are carried out by volunteer recreational divers trained to a scientific level of data collection.

It also links marine scientists, managers and recreational divers, raises public awareness about the health of the inshore environment, and improves community participation in coastal monitoring.

Reef Life Survey provides Australia's most comprehensive, quantitative coastal marine biodiversity baseline data. These support the identification of indicators for change. Standardised surveys now cover more than 3000 species and 1500 sites in Australia and more than 2400 sites worldwide, providing the foundation for a global analysis of how marine protected areas affect the recovery of species. This project analysed the global RLS dataset to identify management features typical of effective marine protected areas (MPAs).

Approach

Many factors influence the rate and magnitude of the recovery of species populations following the declaration of MPAs. They include: MPA size, age, local regulations, fishing pressure, level of compliance, and water temperature. Statistical analysis of data from tens to hundreds of MPAs was required to determine how these factors interact. This project involved analysis of five years of Reef Life Survey data obtained in 87 MPAs and 40 countries: the largest worldwide investigation with standardised quantitative data. Divers used a consistent methodology to survey numbers and sizes of all fishes sighted underwater along 50 m by 5 m transect blocks. Total fish biomass increase in MPAs was used as a proxy for conservation effectiveness.

Key findings

The global analysis found that while some MPAs were extremely effective, more emphasis was needed on MPA design, long-term regulation of fishing practices, and compliance to ensure MPAs achieved their full conservation value. While more than half of the MPAs studied could not be distinguished ecologically from fished areas, fish biomass had been reduced by more than two-thirds on fished reefs worldwide compared with effective MPAs.

Conservation benefits increased exponentially with the accumulation of five key features: regulations that prohibit all fishing, effective enforcement, greater age (>10 years), large size (>100 km^2), and geographic isolation due to deep water or sand. The influence of these five features differed among discrete elements of the reef fish community. MPAs with all five key features had twice as many large (>25 cm) fish species per transect, nine times more large-fish biomass, and 39 times more sharks than fished areas.

LOCATIONS AND NUMBERS OF REEF LIFE SURVEY SITES WORDWIDE

IMAGES: Reef Life Survey

Additional findings

A Reef Life Survey expedition in the Coral Sea Commonwealth Marine Reserve for the Marine Biodiversity Hub found Coral Sea reef animals to be distinctly different from those of the Great Barrier Reef (GBR). This was due to the predominance of species associated with offshore islands, and the presence of fewer fishes and invertebrates typical of the GBR. Overall, Coral Sea reef communities were more closely related to Polynesian reefs than to mainland Queensland reefs, despite vast differences in proximity (see story on page 59).

New knowledge and opportunities

Globally, more than 4500 species of fishes, mammals, sea snakes, turtles, and invertebrates have been assessed, each at about 100 sites on average. More than 2400 sites and 14,000 transect blocks have been surveyed, and the network of trained RLS divers has been broadened.

Reef Life Survey has demonstrated its value in establishing baselines and providing data for evaluating and comparing the status of MPAs: both between MPAs, and with the adjacent environment. It has further potential as an ongoing monitoring tool. Comparative data from the University of Tasmania (IMAS) long-term MPA monitoring program show that fish, invertebrate and macroalgal populations continue to change in MPAs relative to baseline conditions and nearby fished areas for up to 20 years due to interactions within the food web.

Reef Life Survey provides a scientifically rigorous yet cost-effective approach for consistent, long-term Australia-wide monitoring of shallow reef condition that would contribute to State of the Environment reporting.

Outputs and outcomes

This project has delivered improved tools for mapping the distribution of marine biodiversity. Reef Life Survey data have facilitated an improved understanding of the management conditions necessary for MPAs to effectively achieve conservation goals, of threats to marine ecosystems, and of threatened marine species. Public engagement in marine conservation has also been boosted through Reef Life Survey.

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ABOVE: **A Whitetip Reef Shark (*Triaenodon obesus*) at West Islet in the Coral Sea CMR. Marine protected areas with the five key features identified in this project have 39 times more sharks than fished areas.** Image: Reef Life Survey

Supporting biodiversity management across the globe

The United Nations Convention on the Law of the Sea (UNCLOS) provides the international legal framework for using the world's ocean resources.

At present, no global, comprehensive international agreement exists on how biodiversity in areas beyond national jurisdiction (ABNJ) should be managed, conserved or sustainably used. The final meeting of the UN Biodiversity Beyond National Jurisdiction Working Group in early 2015 recommended that the UN General Assembly (UNGA) negotiate a legally-binding instrument, (under UNCLOS), on the conservation and sustainable use of marine biological diversity beyond national jurisdiction.

Notwithstanding the recommendation made by the UN Working Group, the Convention on Biological Diversity (CBD) is undertaking a scientific and technical program to help the international community consider issues related to the conservation and sustainable use of biodiversity in ABNJ.

In this context, Marine Biodiversity Hub scientists have been helping Southern Hemisphere nations to identify areas meeting the scientific criteria established by the CBD for describing Ecologically or Biologically Significant Marine Areas (EBSAs) in the region. Hub scientists provided technical support to a series of Southern Hemisphere CBD workshops that facilitated the scientific description of EBSAs.

EBSAs are areas considered relatively more biologically significant, from a scientific standpoint, than their surroundings. Their scientific identification has produced products and information that can be drawn upon by the international community if they consider implementing spatial management tools, including marine protected areas, in ABNJ.

The global series of regional CBD workshops involved specialists from 92 countries and 79 regional or international bodies. Together, they considered more than two-thirds of the global ocean, and identified more than 200 areas that meet the internationally-agreed definition for EBSAs. The workshops have provided impetus to international discussions of area-based management in ABNJ, and contributed to building capacity and international networks essential to global marine science. The next step is to investigate how EBSA information might support decision-making in relevant UN fora regarding the management, conservation and sustainable use of marine resources in ABNJ.

This project has also supported the ongoing use of EBSAs by proposing an adaptive, hierarchical approach that takes key elements from existing frameworks and demonstrates their application, both within national jurisdictions, and in ABNJ. The adaptive hierarchical process encourages early implementation of marine spatial planning and ecosystem-based management using available scientific knowledge and governance, and supports the gradual progress to more complex and information-rich structures.

ECOLOGICALLY AND BIOLOGICALLY SIGNIFICANT AREAS OF THE GLOBAL OCEAN

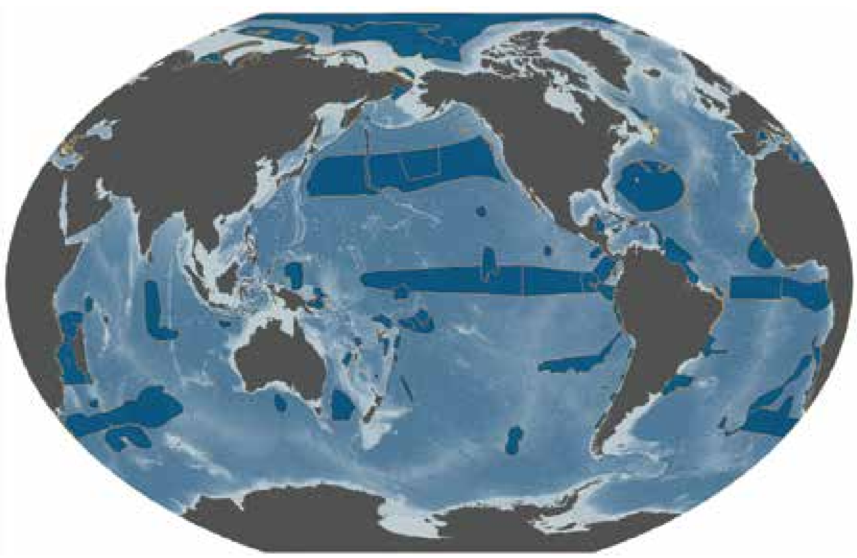

Image: Marine Geospatial Ecology Lab, Duke University

Outputs and outcomes

Southern Hemisphere countries have been supported to identify EBSAs in their own waters and in the regional seas (or ABNJ). In collaboration with the CBD and Duke University teams, the great majority of these areas have been accepted by the international community at the Conference of Parties to the CBD and have been referred to international agencies and conventions including the UN.

Tools developed by the Marine Biodiversity Hub to support marine bioregional planning in Australia have been suggested as options for ABNJ, and have been presented to the CBD and to the United Nations General Assembly Working Group on marine biodiversity in ABNJ. This has provided nations with options and ideas for developing marine protected areas, and moves the discussion beyond the use of EBSAs.

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Supporting Australian aid to Pacific islands and the Coral Triangle

ABOVE: **Regional aid projects must provide enduring regional and local capacity, and support new governance where needed Image: Piers Dunstan.**

Marine Biodiversity Hub scientists are applying knowledge and experience gained during their guiding role in Australia's marine bioregional planning process to support the nation's international interests in marine sustainable development.

They have helped marine planners in the region by translating techniques for identifying and communicating values and threats. To be effective, however, regional aid projects must provide enduring regional and local capacity, and support the development and implementation of new governance where needed. Realistically, this will only come after 10–20 years. Collaboration between the Marine Biodiversity Hub and the Australian Government is providing both the scientific and governance experience required to achieve sustainable outcomes.

Enhancing Pacific Ocean Governance

In 2010, twenty-three Pacific Island leaders endorsed the *Framework for a Pacific Oceanscape*, a conservation and sustainable management framework designed to support regional livelihoods and food security. Implementing the framework requires new knowledge, effectively communicated for a governance framework that has the authority to act. Australia is supporting several actions identified in the Oceanscape framework through the Australian-aid funded Enhancing Pacific Ocean Governance (EPOG) project. Participants include Geoscience Australia, the Attorney-General's Department and Department of the Environment, CSIRO and the University of Sydney.

Hub researchers are working with regional agencies and individual countries as part of the EPOG project. Tools and expertise developed under the Commonwealth Environmental Research Facility (the forerunner of NERP) and NERP marine biodiversity hubs have made significant contributions. Scientists have prepared information for the Department, provided advice on policy drivers, and facilitated an understanding of Key Ecological Features as a means of prioritising monitoring and management.

The experience has allowed Australian scientists, the Secretariat of the Pacific Regional Environment Programme and the Pacific Islands Forum Secretariat to reach rapid agreement on processes fundamental to marine planning. These include the development of a regional information sharing system (now under way) and a process to help individual countries (such as Kiribati) access and use the information to support local marine spatial planning.

Coral Triangle Initiative

Marine Biodiversity Hub scientists are also assisting the Department in its engagement with the Coral Triangle Initiative, which supports coral reef protection and management across six countries: Indonesia, the Philippines, Malaysia, Papua New Guinea, the Solomon Islands and Timor-Leste. Existing and new ecological and socio-economic datasets are being linked to foster an improved understanding of key regional-scale and transboundary issues, particularly those relating to Regional Goal 1 of the Regional Plan of Action: 'Priority seascapes designated and effectively managed'. Coastal livelihoods, climate, resource management and deep sea mining are issues under consideration.

This ongoing project will support improved marine management by helping governments to understand the distribution of biological assets and the means by which activities at a local scale could be integrated into national policy.

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Marine Biodiversity Hub researchers are working with the Australian Government, the Secretariat of the Pacific Community and the University of Wollongong to provide options for developing regional governance to support existing community-based fisheries in Kiribati. Image: Piers Dunstan

Monitoring pelagic fish: from Australia to the Austral Islands

Non-destructive sampling methods are needed to provide quantitative data on the population status of pelagic sharks and fishes, particularly in marine reserves and other areas where fisheries catch data are unavailable.

This project developed non-destructive techniques for monitoring pelagic sharks and fishes. It contributed to the development of baselines for pelagic shark and fish assemblages in Commonwealth Marine Reserves (CMRs), as well as in other areas of interest to the international community. Mid-water camera systems developed in this project have been used during pelagic expeditions supported by the National Geographic Pristine Seas initiative (see story on page 70).

Approach

Approaches to sampling pelagic shark and fish assemblages were reviewed and non-destructive mid-water stereo video camera systems for collecting quantitative data were developed and tested. NERP Marine Biodiversity Hub field surveys conducted to establish pelagic baselines in new CMRs (Oceanic Shoals CMR and Perth Canyon CMR) provided ideal testing grounds.

The mid-water camera rigs consist of a supported, horizontal bar on which two cameras are mounted in fixed housings. A system of floats maintains buoyancy and stability and a bait canister is held by a horizontal arm.

Video imagery is analysed using custom software to determine species richness and abundance, as well as the length of individual animals. These data are used for monitoring changes in the diversity, abundance and size structure of pelagic shark and fish assemblages.

The success of the new systems led to further involvement in international surveys for pelagic sharks and fishes and other wildlife. In 2012–2014, expeditions were made to Chagos Archipelago, New Caledonia, Palau, Tonga, and Rapa/Marotiri, and Gambier islands in French Polynesia, with support from international partners.

Key findings

Mid-water stereo video camera systems can effectively quantify characteristics of pelagic shark and fish assemblages such as species diversity, abundance and size structure. As a non-destructive technique, the method is appropriate for monitoring marine protected areas.

Mid-water stereo video camera systems are a cost-effective, highly versatile technique that can be deployed from a variety of platforms (small tenders to large oceanographic vessels), in varying configurations (moored, drifting), and combined with complementary techniques such as acoustics, depending on monitoring requirements.

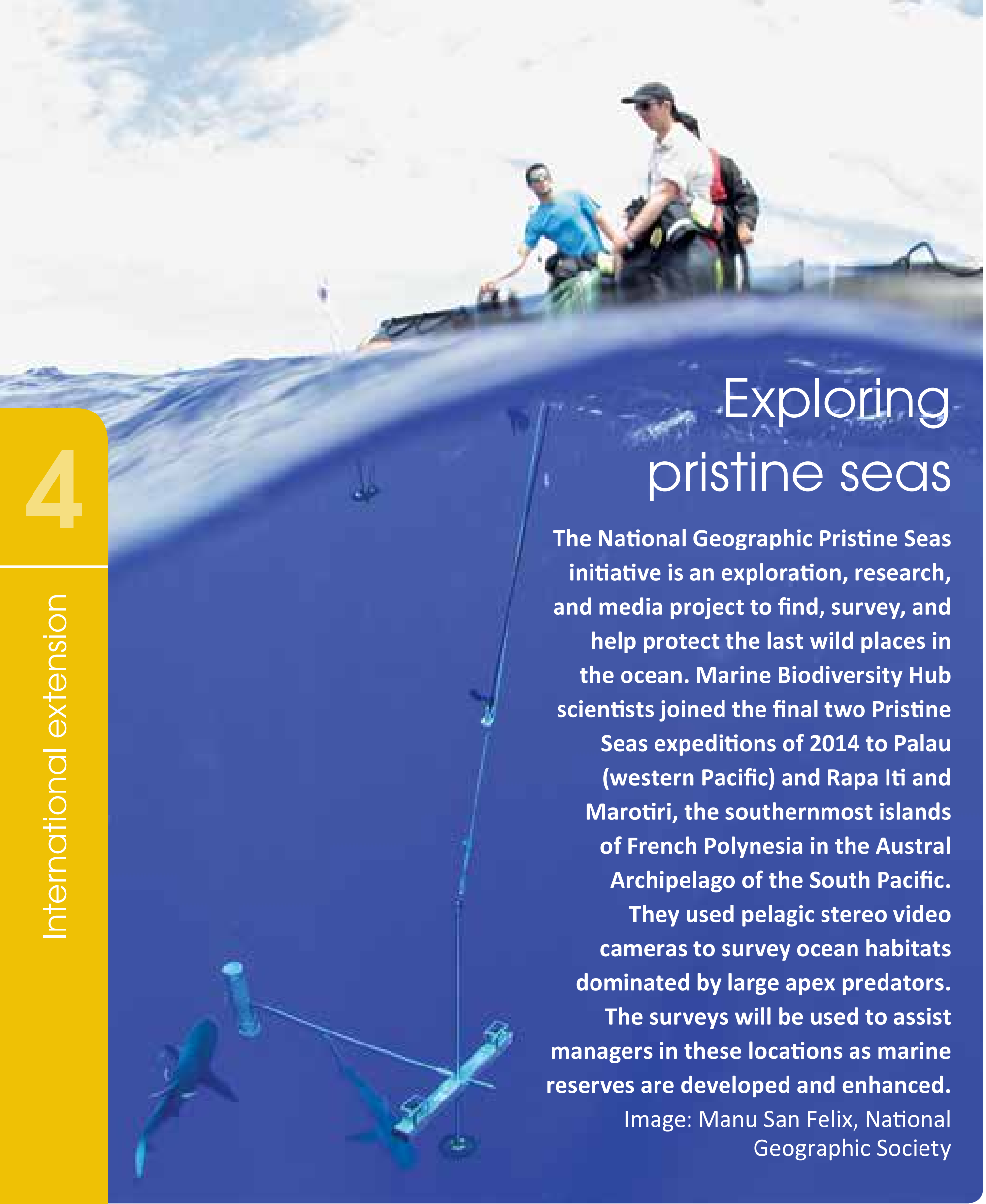
Estimates of species richness and abundance generated by mid-water stereo video camera systems support the design of MPAs by identifying pelagic hotspots. The estimates also contribute to establishing baselines for MPA monitoring and other applications such as environmental impact assessments.

Pelagic assemblages, as unveiled by mid-water stereo video camera systems, are diverse, and include a wide range of animals from juvenile reef fishes in their pre-recruitment phase to large marine animals such as tunas, oceanic sharks, and orcas.

New knowledge and opportunities

Mid-water stereo video camera systems can be used to collect baseline data on pelagic species that can contribute to assessing the effectiveness of Australia's CMR network and international MPAs. The expanding use of mid-water stereo video

A Galapagos Shark (*Carcharhinus galapagensis*) bumps the bait canister of the mid-water stereo video camera system. Image: Manu San Felix, National Geographic Society



Exploring pristine seas

The National Geographic Pristine Seas initiative is an exploration, research, and media project to find, survey, and help protect the last wild places in the ocean. Marine Biodiversity Hub scientists joined the final two Pristine Seas expeditions of 2014 to Palau (western Pacific) and Rapa Iti and Marotiri, the southernmost islands of French Polynesia in the Austral Archipelago of the South Pacific. They used pelagic stereo video cameras to survey ocean habitats dominated by large apex predators. The surveys will be used to assist managers in these locations as marine reserves are developed and enhanced.

Image: Manu San Felix, National Geographic Society

camera systems will enable the status of Australia's pelagic assemblages to be evaluated in an international context.

Outputs and outcomes

This project developed new techniques to estimate the abundance and species richness of pelagic fish in marine reserves. This information may be useful in assessing performance of CMRs. Stereo video camera systems have collected pelagic fish and shark imagery and data at:

- Shark Bay, WA;
- Perth Canyon CMR, WA;
- Oceanic Shoals CMR, Timor Sea;
- Chagos Archipelago, central Indian Ocean;
- Palau, western Pacific;
- New Caledonia, western Pacific;
- Rapa/Marotiri, western Pacific;
- French Polynesia, central Pacific; and
- Tonga, central Pacific.

A compilation of high-quality video footage from the Perth Canyon CMR is available online, supported by a grant from the Australian Academy of Science through its Margaret Middleton Fund Award for field-based ecological research on endangered Australian vertebrates.

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IMAGE: Reef Life Survey

Science leader reflections

Theme 1 • Keith Hayes

National monitoring evaluation and reporting

Existing information, methods and capabilities were harnessed in this research theme to develop a blueprint for a sustained national monitoring strategy targeting Key Ecological Features (KEFs) in Australia's Commonwealth waters.

New methods were devised for survey design, and for analysing data from non-extractive sampling techniques: part of the toolkit required for a national monitoring program. A novel marine application of the Generalised Random Tessellation Stratified survey design was successfully trialled in Commonwealth marine reserves (CMRs) and KEFs in Commonwealth waters east of the Abrolhos Islands were mapped. Shelf rocky reef systems, demersal fish and benthic invertebrate communities were identified in the Flinders CMR, the Abrolhos KEF, the Solitary Islands KEF and the Geographe CMR. More than 110 km^2 of additional high-resolution multibeam sonar data were acquired in the Solitary Islands KEF, Flinders CMR and Tasman Fracture CMR.

Research in this theme examined how marine reserves affect the marine environment, how to use drop cameras in combination with baited remote underwater video systems to simultaneously assess fish communities and habitat distribution, and how management activities are affecting habitats and fish communities. Existing data were used to identify productivity trends in enhanced-pelagic-productivity KEFs, and to test qualitative model predictions for rock lobster, urchin and kelp communities in Tasmania's Maria Island marine reserves.

A national nomenclature standard was developed for labelling habitat features and organisms in marine imagery and a national data catalogue, ARMARDA, was built to visualise biological and oceanographic datasets collected at KEFs and CMRs. This facility was developed to identify any consistently collected data useful for monitoring KEFs and CMRs.

End-user engagement

Scientists engaged with the Department of the Environment to help articulate priority management questions relating to the health of the Australia's Commonwealth waters (subsequently progressed in the national monitoring blueprint). A shared understanding was reached of the need for robust survey designs and flexible monitoring programs to accommodate variability in funding and research capacity.

Building capacity

Experience has been gained in designing and implementing surveys in waters beyond depths accessible to divers, with the built-in flexibility necessary for a long-term monitoring program. Additional expertise and novel analytical methods have been developed to analyse spatial correlation and temporal trends in marine imagery data. This was achieved through a highly collaborative approach that made use of the individual capabilities of Hub partners and collaborators.

Impact

This research theme has developed a scientific perspective on how to proceed with a national marine monitoring program, as well as practical tools to support its implementation. Resource managers will require further information and guidance as they work to incorporate this scientific foundation in an enduring national program for monitoring the performance of the CMR network and marine ecosystem health more generally.

Outputs from this theme contributed to an integrated monitoring framework for the Great Barrier Reef World Heritage Area.

Research partners

- Australian Centre for Field Robotics, The University of Sydney
- Australian Institute of Marine Science
- CSIRO
- Department of Fisheries Western Australia
- Geoscience Australia
- Integrated Marine Observing System
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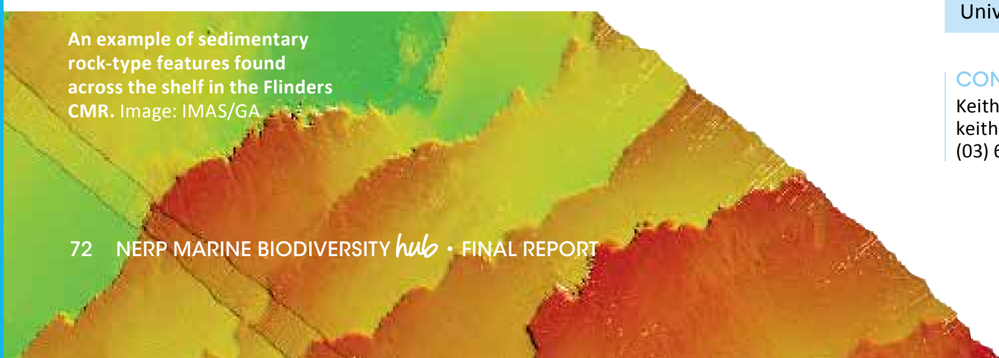

An example of sedimentary rock-type features found across the shelf in the Flinders CMR. Image: IMAS/GA

Theme 2 • Tony Smith

Supporting management of marine biodiversity

This theme explored methods and tools for valuing marine biodiversity, identifying threats, and evaluating approaches to conservation management.

Tools and analyses were designed to support the implementation of marine bioregional plans, monitoring the South-east Commonwealth Marine Reserves (SECMR) Network, and assessment and management of listed species under the *Environment Protection and Biodiversity Conservation Act 1999.*

End-user engagement

Research in this theme focused on stated needs of the Department of the Environment. Scientists and departmental representatives engaged through workshops, briefing sessions, seminars, and one-on-one meetings to shape individual projects. In some cases, however, changes in the policy environment led to Departmental priorities changing and this complicated the definition of relevant projects. The result was that while some projects appear to have satisfied Departmental needs, others experienced delays and frustration, and this affected the potential uptake of research findings. For example, trying to finalise objectives for the research focussed on integrating social, economic and environmental values was difficult, and progress has been delayed as a result.

Building capacity

Regional scale quantitative analysis of pressures and cumulative impacts on seabed fauna led to the first quantitative evaluation of conservation management strategies and trade-offs for this area. This capacity to evaluate existing and potential alternative biodiversity management options on and off reserves, as well as the relative impact of alternative pressures including marine industries, can be used to support evidence-based decision making in these difficult-to-observe offshore environments.

Landscape approaches to managing high-priority conservation values focussed on the SECMR and shark species of temperate Australia. Extensive data integration led to improved knowledge and understanding of demersal shark distribution and of important areas where several species overlap. Research infrastructure and capabilities developed during this project will support ongoing monitoring and assessment of sawfishes and river sharks in the Northern Territory, and of species such as White Sharks around Australia. New close kin mark-recapture methods provide a quantum leap in the capability to assess threatened species.

Largetooth Sawfish. Image: Peter Kyne

Issues associated with the design and implementation of marine biodiversity offsets were explored. These included the performance of offsetting strategies in the presence of cumulative impacts, and community preferences for aspects of offset design.

Impact

Specific advice on protected species and biodiversity management has been used by the Department, such as to support non-detriment findings for sawfish in northern Australia. The longer term impact of the close-kin methods applied to river sharks and White Sharks is likely to be large when applied to a range of threatened marine species.

Nevertheless, given the focus and aims of this theme, the overall level of impact has been less than anticipated. Difficulty in specifying needs and objectives, and changing priorities, has led to delays and frustrations. This experience points to the need for early dialogue and continuing communication so that there is shared understanding of how projects will meet the Department's needs.

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Science leader reflections

Project profile
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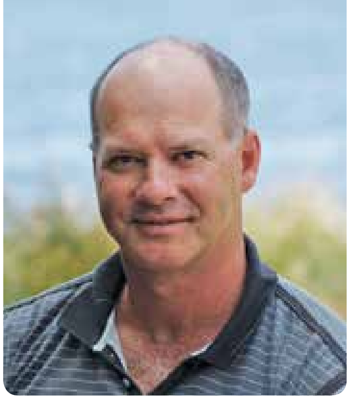
- Barry Bruce



Supporting management and recovery of threatened species

Threatened species research started as a relatively small development project on euryhaline elasmobranchs under Theme 2, but early promising results led to the addition of emerging priority research on White Sharks.

The project investigated the distribution, movements, habitat use and status of threatened sawfishes, river sharks and White Sharks, including options to effectively assess and monitor the status of threatened species. It provided world-first abundance estimates for White Sharks and Speartooth Sharks, and developed novel molecular and statistical tools for estimating demographic parameters, abundance and population status.

End-user engagement

Working through the NERP Marine Biodiversity Hub gave us an unprecedented level of collaboration and communication, both between research partners, and with the Department of the Environment. A team of scientists with ecological, technical, and resource management expertise provided diverse research capacity, and regular communication made a strong contribution to policy making and management. For example, expert advice was provided on updating species recovery plans, assessments of proposed developments for their effect on threatened species, and on Australian submissions to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species.

Building capacity

Research tools developed during this work ranged from the molecular to the landscape scale and included species-level ecological and technical expertise essential for designing future monitoring programs. Cutting-edge genetic and statistical techniques (close-kin mark-recapture) were developed and applied to key management questions. Extensive arrays of acoustic receivers (130 receivers) were deployed in seven Northern Territory and Queensland river systems to monitor tagged animals (10 species and some 400 individuals). These arrays and tagged individuals will provide data for up to five more years. Tagged juvenile White Sharks will also provide ongoing movement data for population modelling, via acoustic receivers spanning Australia's east coast.

Impact

This research provided up-to-date information to assist in mapping, monitoring, assessments and referrals. It also identified for the first time practical options for monitoring and assessing 'difficult to assess' aquatic threatened species.

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Flinders University
Griffith University
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Kakadu National Park
Malak Malak Traditional Owners and Ranger Group
Melbourne Aquarium
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Peter Kyne conducts field work on the Adelaide River, NT. Image: Mat Gilfedder

Theme 3 • Scott Nichol

National ecosystems knowledge

This theme delivered new datasets and models that characterise large-scale processes influencing marine biodiversity patterns on a national scale. It focused on areas prioritised by the Department of the Environment through marine bioregional planning, such as the Commonwealth Marine Reserve network.

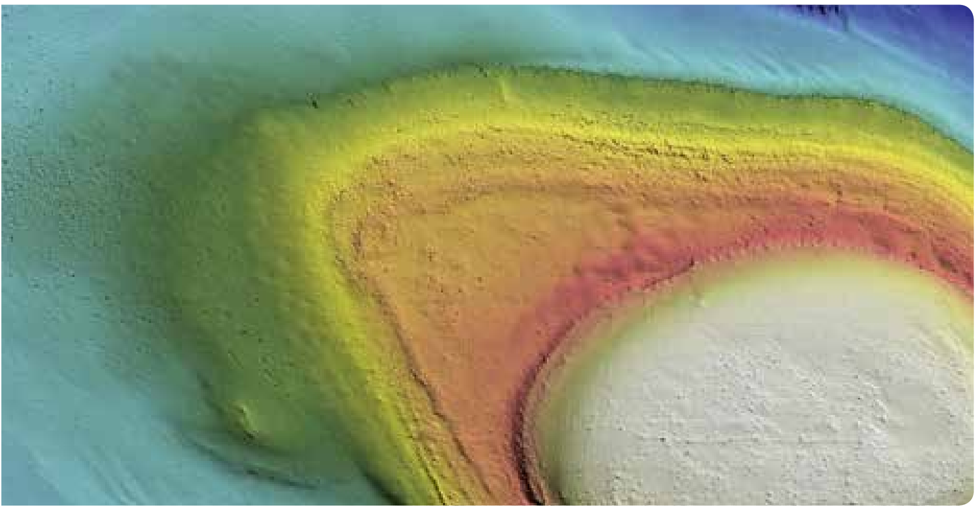
A larval dispersal model was developed to help understand connectivity across the marine estate, with a focus on Key Ecological Features and marine protected areas. The theme also produced new genetic data on the taxonomy of brittle stars and squat lobsters to better understand biogeographic patterns of benthic biodiversity, nationally and globally.

Thirty-six national marine datasets (new and updated) were compiled and published. These included descriptions of sea floor topography and sediments, submarine canyons, sea-surface water quality and seabed exposure to waves and currents, as well as national catalogues of marine biota, including rare and threatened species.

New insights into seafloor processes associated with physical features on the continental shelf (reefs, bank, pinnacles, canyon heads) were gleaned from field research undertaken in themes 1 and 4, particularly the expedition to Oceanic Shoals Commonwealth Marine Reserve, where hard-ground reefs influenced seafloor biological communities and fish aggregations.

End-user engagement

Representatives from the Department were engaged in meetings and discussions to share progress reports and highlights. The engagement built trust and understanding, and facilitated the collaborative development of summary documents and provision of data through the Australian Ocean Data Network.



ABOVE: **High resolution multibeam sonar image of the seabed in the Oceanic Shoals Commonwealth Marine Reserve.** Image: Geoscience Australia

Building capacity

High performance computing and satellite data analysis was developed and applied to modelling connectivity and sea-surface dynamics, and gene sequencing and machine learning methods were applied to understanding biogeographic structure and benthic biodiversity prediction.

Impact

Continuing engagement with the Department has ensured the accessibility and utility of research outputs. Further improvements are possible by increasing the direct links between departmental and research data systems. Models and datasets produced in this theme have been used by researchers inside and outside the Marine Biodiversity Hub.

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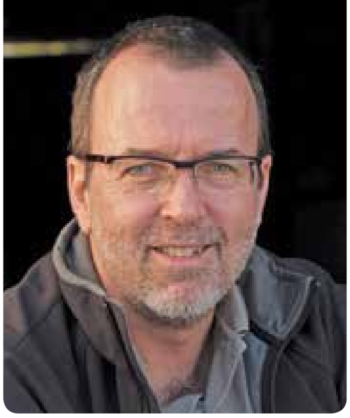

Theme 4 • Julian Caley

Regional biodiversity discovery to support marine bioregional plans

Strong, national, multidisciplinary collaboration in marine science was exercised and developed in this theme to better understand Australia's north and north-west marine regions.

Sparse data are available to support effective management of these vast areas, which face increasing cumulative pressures from environmental change and extractive industries, including fisheries and oil and gas.

High-resolution bathymetry, geochemical and geophysical data, and biological collections and observations contributed to a qualitative model of the Key Ecological Features (KEFs) of the Oceanic Shoals Commonwealth Marine Reserve that confirmed their biodiversity value and regional significance.

End-user engagement

Consultation with the Department of the Environment helped to prioritise theme priorities to support management needs to understand the value of KEFs in a regional context and to explore unsurveyed areas of a recently declared Commonwealth Marine Reserve. Visual outputs from surveys, including pictures and videos, proved useful for communicating with the Department and a broader audience. A video developed by the Marine Biodiversity Hub that featured research footage and modelling to highlight the values of a Commonwealth Marine Reserve was used by the Department at the IUCN World Parks Congress (Sydney 2014). Pelagic camera highlights and a brochure about the Oceanic Shoals voyage were also produced.

Building capacity

Research partners combined unique expertise to survey some 600 km² of seabed containing KEF (banks, pinnacles and shoals) and non-KEF habitats. Multibeam sonar and other acoustic tools were used to create high-resolution seabed maps and biological material was sampled with epibenthic sleds. Seabed habitats and fish communities were observed with towed cameras and benthic and pelagic baited video systems. The survey, processing and analysis provided training for doctoral and post-doctoral students, established new sample and data collections, and successfully trialled new, non-destructive, sampling methodologies such as pelagic baited cameras. It also discovered more than 150 km² of new KEF habitat in the Oceanic Shoals CMR.

Impact

Research in this theme designed and delivered information products to support priority needs identified by the Department. The field expedition supported the roll-out of standardised survey and monitoring protocols including the Generalised Random Tessellated Stratified technique for selecting survey sites, and the application of standardised and new methods for environmental and biodiversity sampling. It also provided new information that was used to develop the first qualitative model of the KEFs in the area, a departmental goal for all the KEFs identified across the CMR network and a prerequisite to their inclusion in national marine ecosystem health monitoring.

www.nerpmarine.edu.au/rv-solander-blog

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BELOW: **Mid-water stereo video camera systems were among a suite non-destructive sampling methodologies developed to survey marine habitats and fish communities.** Image: University of Western Australia

People and publications

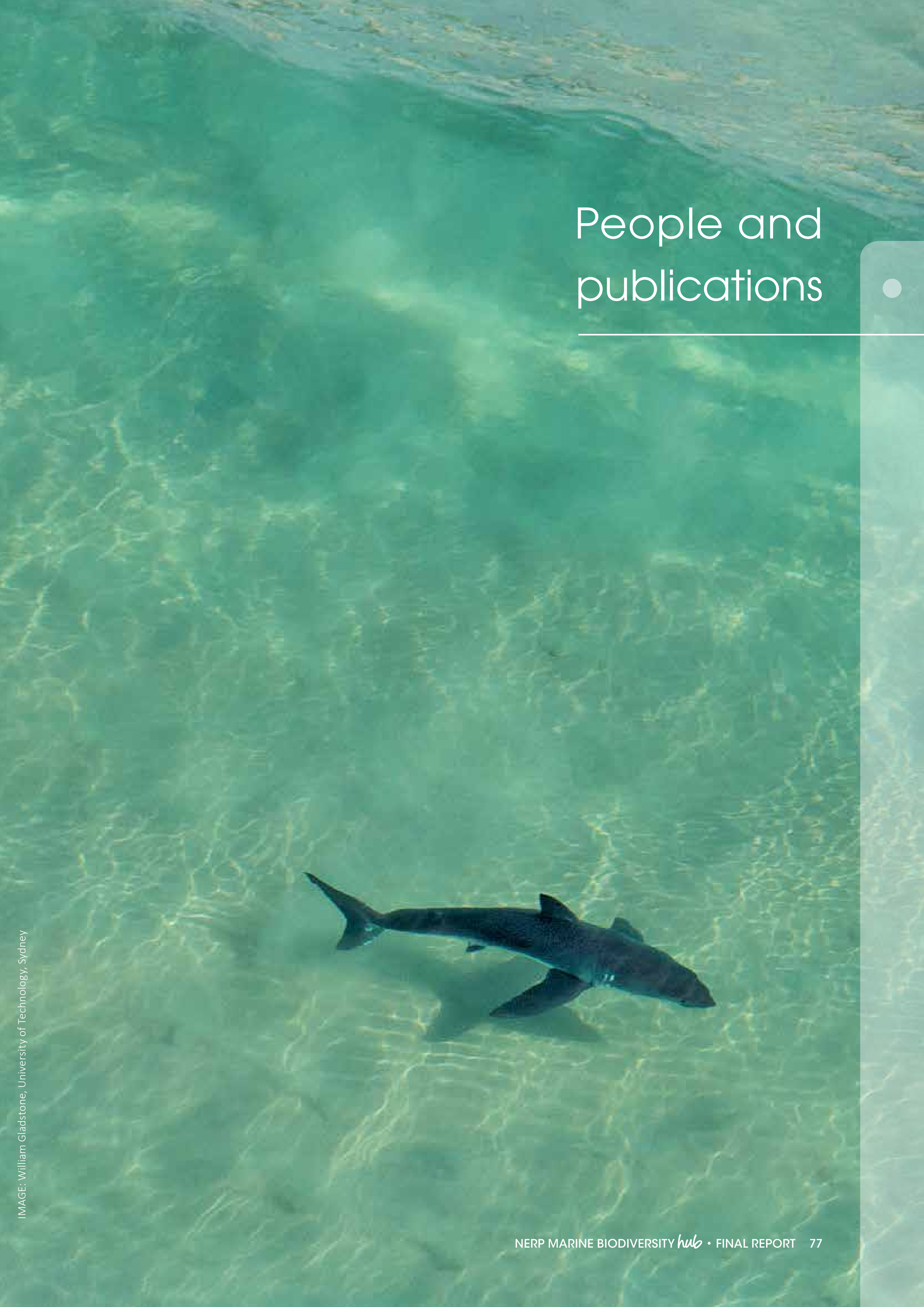
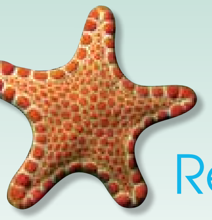


IMAGE: William Gladstone, University of Technology, Sydney



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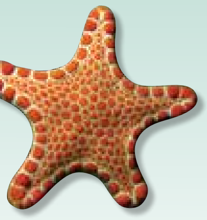
Images: William Gladstone, UTS



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Publications

IMAGE: William Gladstone, UTS

Publications

Funded by the National Environmental Research Program

(includes peer reviewed articles – submitted, in review, accepted, in press, published)

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Bird Island Reef. Image: Reef Life Survey

IMAGE: Reef Life Survey

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