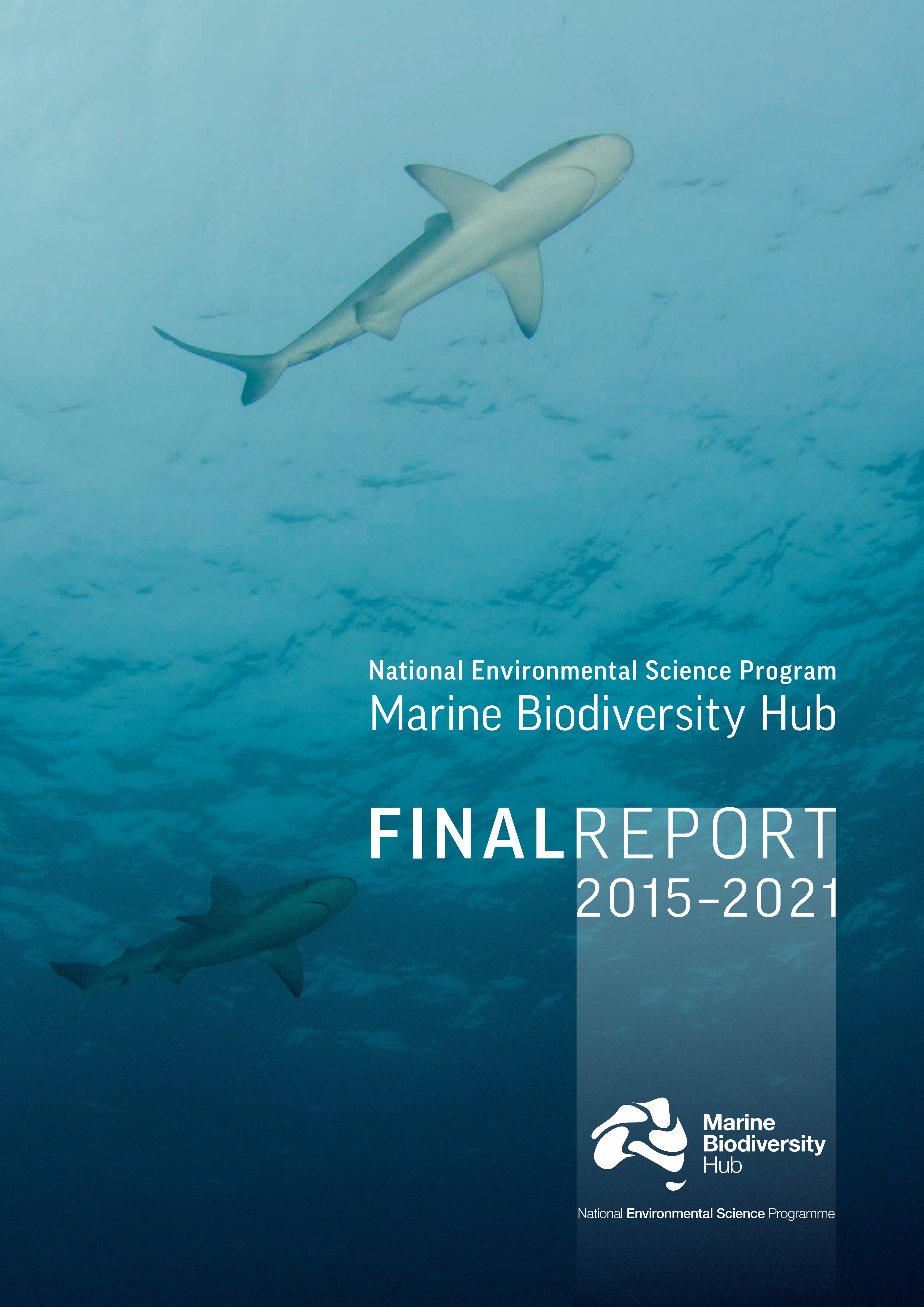


National Environmental Science Program

Marine Biodiversity Hub

FINAL REPORT 2015–2021

Marine Biodiversity Hub

National Environmental Science Programme

Acknowledgement

This work was undertaken by the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Research Program (NESP).

Disclaimer

The NESP Marine Biodiversity Hub advises that the information contained in this publication comprises general statements based on scientific research.

The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, the NESP Marine Biodiversity Hub (including its host organisation, employees, partners and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Copyright

Preferred citation

Jordan A and Hedge P [Eds]. (2022) *National Environmental Science Program Marine Biodiversity Hub Final Report 2015–2021*. Report to the Department of Agriculture, Water and the Environment. Canberra, Australia.

Marine Biodiversity Hub Partners

National Environmental Science Program
Australian Institute of Marine Science
Charles Darwin University
CSIRO
Geoscience Australia
Integrated Marine Observing System
Museums Victoria
New South Wales Government
University of Tasmania
The University of Western Australia

Enquiries

Dr Alan Jordan
Director
Marine Biodiversity Hub
Institute for Marine and Antarctic Studies
University of Tasmania
alan.jordan@utas.edu.au

Design and production: Bryony Bennett and Louise Bell

FINALREPORT 2015–2021

Research for understanding and managing Australia's marine biodiversity

OCTOBER 2022

www.nespmarine.edu.au

National Library of Australia Cataloguing-in-Publication entry

Title: National Environmental Science Program Marine Biodiversity Hub Final Report 2015–2021

ISBN

978-0-646-86120-3 (print)
978-0-646-86121-0 (ebook: pdf)

Subjects

Marine biodiversity conservation–Australia–Management
Endangered species–Australia–Management
Environmental monitoring–Australia
Marine resources–Australia–Management
Marine parks–Australia–Management
Coastal restoration–Australia–Management

Dewey number: 578.770994

FRONT COVER: **Middleton Reef.** Image: Antonia Cooper
INSIDE FRONT: **The *Bluefin* at Winter Cove.** Image: Neville Barrett
CONTENTS: **Malak Malak Ranger Rob Lindsay seeking Largetooth Sawfish on the Daly River floodplain.** Image: Michael Lawrence-Taylor

Contents

Deep seafloor habitat pictured during the Seamount Corals Survey 2018. Image: CSIRO Marine National Facility

Peter Cochrane

Chairman’s foreword

This third iteration of the Marine Biodiversity Hub with its 10 research partners has impressively built on and extended the reach, utility and impact of its two predecessors.

This continuity and growth of effort has enabled and supported a diversity of collaborations within the research community, and even more importantly with a growing diversity of research users and decision-makers, while maintaining the Hub’s primary focus on national research priorities and the needs of the federal environment department.

Initially focusing on discovery and description of Australia’s rich and diverse marine biodiversity, the Hub’s remit has evolved to embrace monitoring, recovery and restoration, and improving our understanding of and responses to human use and impacts, particularly in the context of a rapidly changing climate and a warming ocean.

The Hub’s wide-ranging outputs reflect the diversity of its collaborations, significantly improving the state of knowledge of our oceans and contributing to the growing awareness and appreciation of the economic, social, cultural and environmental values of our marine environment. These outputs range from the development of standard operating protocols for surveying and monitoring and data handling – enabling the consistent collection and aggregation of data from different sources; habitat maps and predictive tools for species distributions, abundances and recovery plans; national overviews of marine resources and pressures; and condition and trend data for the marine chapters of successive State of the Environment reports.

The building of trusted and enduring relationships with research users and policy makers; the delivery of high quality research and applied products; the commitment to open and accessible data and research findings; and the growing respect for and engagement with Indigenous peoples and communities have been signature features of the Hub over its 15 years. These are a testament to the leadership of Hub directors Nic Bax and Alan Jordan, and Paul Hedge the Hub’s indefatigable knowledge broker.

The Hub’s success is due to the work of many – partners, researchers, research users and decision-makers. I make special mention of Hub’s research partners and their participation in the Hub Steering Committee, the unfailing support from the University of Tasmania that has hosted the Hub since its beginnings in 2007, and the Australian government environment portfolio and staff therein that have through many iterations and changes of name and ministers steadfastly maintained their support and funding for environmental research to inform better decision-making.

STEERING COMMITTEE

CHAIR Peter Cochrane

HUB EXECUTIVE
Alan Jordan
Director Mar 2020–Jun 2021
Nic Bax
Director Jan 2015–Mar 2020
Paul Hedge
Deputy Director, Knowledge Broker
Sarah Gracie
Executive Officer
University of Tasmania

David Souter
Australian Institute of Marine Science

Karen Gibb
Charles Darwin University

Trevor Dhu
Geoscience Australia

Terry Bailey
University of Tasmania

Gary Kendrick
The University of Western Australia

Jeanette Corbitt (NESP Program)
Ilona Stobutzki
Jason Mundy (Parks Australia)
Department of Agriculture, Water and the Environment

Stan Lui
Torres Strait Regional Authority

Alan Jordan

Director's overview

The National Environmental Science Program Marine Biodiversity Hub provided evidence and tools to help the Australian Government, state governments, stakeholders and the broader community to better understand, manage and conserve Australia's marine environment.

This collaborative research built on the achievements of two previous Hub funding programs: the Commonwealth Environment Research Facilities Program and the National Environmental Research Program.

Through its 10 research partners, the Hub established a network of research agencies, research-users and Indigenous communities to identify and address priority needs. The focus was on Australian Marine Parks (AMPs), sustainable resource use, threatened and migratory species and coastal habitat restoration. Research across these themes was underpinned by the development of nationally consistent approaches designed to strengthen Australia's marine research coordination and capability.

Multi-agency surveys supported by the Hub established bathymetric and ecological baselines in tropical and temperate AMPs. The surveys advanced technologies such as swath acoustics, remotely operated vehicles and stereo underwater cameras. They facilitated the development and application of national standards for data acquisition, sharing and visualisation, transforming the accessibility and utility of research findings for researchers and research-users. Other projects created social and economic benchmarks for AMPs, and mapped activities and pressures on natural values.

The new knowledge has been central to understanding and promoting AMP values, assessing risks, identifying indicators of ecosystem values and pressures, and, ultimately, management and monitoring priorities. Effective collaboration between researchers and marine park managers raised the bar for achievements with co-designed and co-delivered practical research for AMPs.

For waters beyond AMPs, the Hub consolidated existing knowledge and developed mapping and predictive tools to better understand natural values, pressures and risks. Shallow-reef biodiversity state and trends, and the effects of ship noise and vessel strikes on large marine animals were explored at a national scale. The National Outfall Database provided the first snapshot of wastewater discharges around Australia.

Hub research supported the recovery and conservation of threatened and migratory marine species including White Sharks, sea snakes, Southern Right Whales, inshore tropical dolphins and handfishes. These projects helped Australia to implement regional, national and international conservation policies. A key product was *The Action Plan for Australian Sharks and Rays 2021*: a comprehensive and consistent review of the extinction risk of all Australian sharks, rays and chimaeras. Related research on threatened northern Australian sharks benefitted greatly from Indigenous knowledge and participation.

Coastal habitat restoration was another area of important development during the Hub. Research investment is generating national capacity and a better evidence base to target and accelerate restoration research. This includes evaluating restoration practices and economics, working with traditional owners, and supporting platforms for knowledge sharing among policy makers, practitioners and communities.

RESEARCH LEADERSHIP TEAM

HUB EXECUTIVE
Alan Jordan
Paul Hedge
Sarah Gracie
University of Tasmania

PROGRAM LEADERS

Michelle Heupel
Michele Thums
Australian Institute of Marine Science

Peter Kyne
Charles Darwin University

Piers Dunstan,
Keith Hayes
CSIRO

Scott Nichol
Geoscience Australia

Neville Barrett
University of Tasmania

Several of the Hub's regional projects partnered with Indigenous communities to identify and advance Indigenous research interests and priorities. This engagement and knowledge sharing contributed to empowering Indigenous people in land and sea research and management. At the national level, partnerships were championed through annual Indigenous engagement workshops organised through the Australian Marine Science Association.

Overall, the Hub made an important contribution to Australia's national approach for advancing a sustainable blue economy. It was both strategic and pragmatic, and provided collaborative opportunities of benefit to research-users and stakeholders with an interest in managing and conserving Australia's marine environment. This report showcases Hub research that contributed to the national evidence-base required to support effective marine management.

Paul Hedge

Knowledge broker's overview

Research conducted by the Marine Biodiversity Hub provided foundational scientific evidence for biodiversity conservation and sustainable use in Australia's marine environment.

Knowledge brokering was an integral part of the Hub's approach, ensuring projects were collaboratively designed and implemented to deliver fit-for-purpose products to meet the specific needs of end-users, in particular the Australian Government and its stakeholders.

Setting priorities for sharing knowledge

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 Hub's governance committees, the Director, project leaders and research end-users to develop and implement the Hub's Knowledge Brokering Strategy. A broad group of scientists, policy makers, managers and communicators were involved in developing and exchanging knowledge, including the Hub's Steering Committee, project leaders, senior executives, policy officers, marine park managers, technicians and data managers.

Knowledge brokering under the NESP built on the Hub's successes in the previous funding program (the National Environmental Research Program). Under the previous program, knowledge brokering was typically planned and implemented centrally by the knowledge broker, Director and Research Leadership Team. Under NESP, we advanced our approach to increase knowledge brokering responsibilities for project leaders and their research teams. This was considered an important step in transitioning to a larger more complex research program, including the need to develop the research portfolio to include a greater number of Indigenous research partnerships.

An important consideration for advancing our approach to knowledge brokering was identifying priority projects for larger, more considered knowledge brokering investments. Priorities for investment were typically complex projects, such those with links to numerous other projects or a broad spectrum of research end-users, or projects scoped to inform decision making in areas where policy is evolving or broadly specified. Priorities for investment where also informed by levels of project team experience in knowledge brokering and past performance.

Investing in trust, co-design and flexibility

Knowledge brokering was embraced by Hub researchers and research-end-users, and this was key to the delivery of high-impact research for biodiversity conservation and sustainable use in Australia's marine environment. Increasing responsibilities of knowledge brokering for project leaders and research teams has increased capability among the Hub's partners and research end-users. This is clearly evident in the area of marine monitoring where we forged an unprecedented level of coordination, information sharing and understanding among Australia's researchers, marine park managers and operational staff, scientists and infrastructure managers.

This enduring investment in developing trusted relationships and knowledge exchange essentially established the policy and science building blocks of a management effectiveness system for adaptive management of the world's largest representative marine park network.

The knowledge broker performed a key role in promoting investments in Indigenous engagement and participation in research and this has provided benefits to many Indigenous people across a range of communities by offering employment and training opportunities. It has also improved understanding and capacity in Australia's marine science community about the importance of Indigenous engagement and how to establish partnerships in a culturally appropriate and respectful way.

Important aspects of knowledge brokering for advancing marine monitoring and Indigenous partnerships were co-design, regular reviews of project progress and risk management and co-development of research products. Adopting flexible and collaborative approaches to setting project timelines and developing co-designed research products was often critical for delivering high impact research.

Testimonials

Jason Mundy, Acting Division Head of Parks Australia.

Dr Ilse Kiessling, Assistant Secretary, Protected Species and Communities Branch, Department of Climate Change, Energy, the Environment and Water.

Dr Chris Gillies, Managing Director, SeaGen Aquaculture (formerly Oceans Director, The Nature Conservancy).

Section 1 Australian Marine Parks

Parks Australia manages the Australian Marine Parks (AMPS) – one of the world's largest networks of marine protected areas. Our understanding and management of the parks has been greatly enhanced by our collaboration with the Marine Biodiversity Hub and its partner organisations. A process for determining the most important information to collect to evaluate the effectiveness of park management was identified and piloted in the South-east Network. Ecological surveys in several parks mapped the distribution of natural values and provided baselines for evaluating the effectiveness of park management. Social surveys established baselines for awareness, use, perceptions and economic value of AMPS.

Section 6 Data

Access to quality scientific information presented in ways that support park manager decision making is critical for managing AMPS. The Marine Biodiversity Hub made important steps towards achieving this. Firstly, by developing best practice approaches for collecting robust and comparable environmental and biodiversity data. Secondly, by collating data for reefs on the Australian continental shelf, reef biodiversity data for the temperate shelf reefs, and national pressure data for a diverse range of activities. Thirdly, by developing and improving data delivery through a variety of online portals.

Jason Mundy

Section 4 Recovery and assessment of threatened and migratory species

The research undertaken through the Marine Biodiversity Hub over the last 14 years has played a critical role in improving our understanding of threatened marine species. The Department is grateful to the many Hub contributors whose collaborative efforts have provided a wealth of new information on Australia's marine fauna and helped guide protection and management action. As just a few of many examples, the Hub's first national Action Plan for sharks and rays, rigorous population estimates of threatened sharks, and innovative research on sawfish have helped to drive significant conservation outcomes.

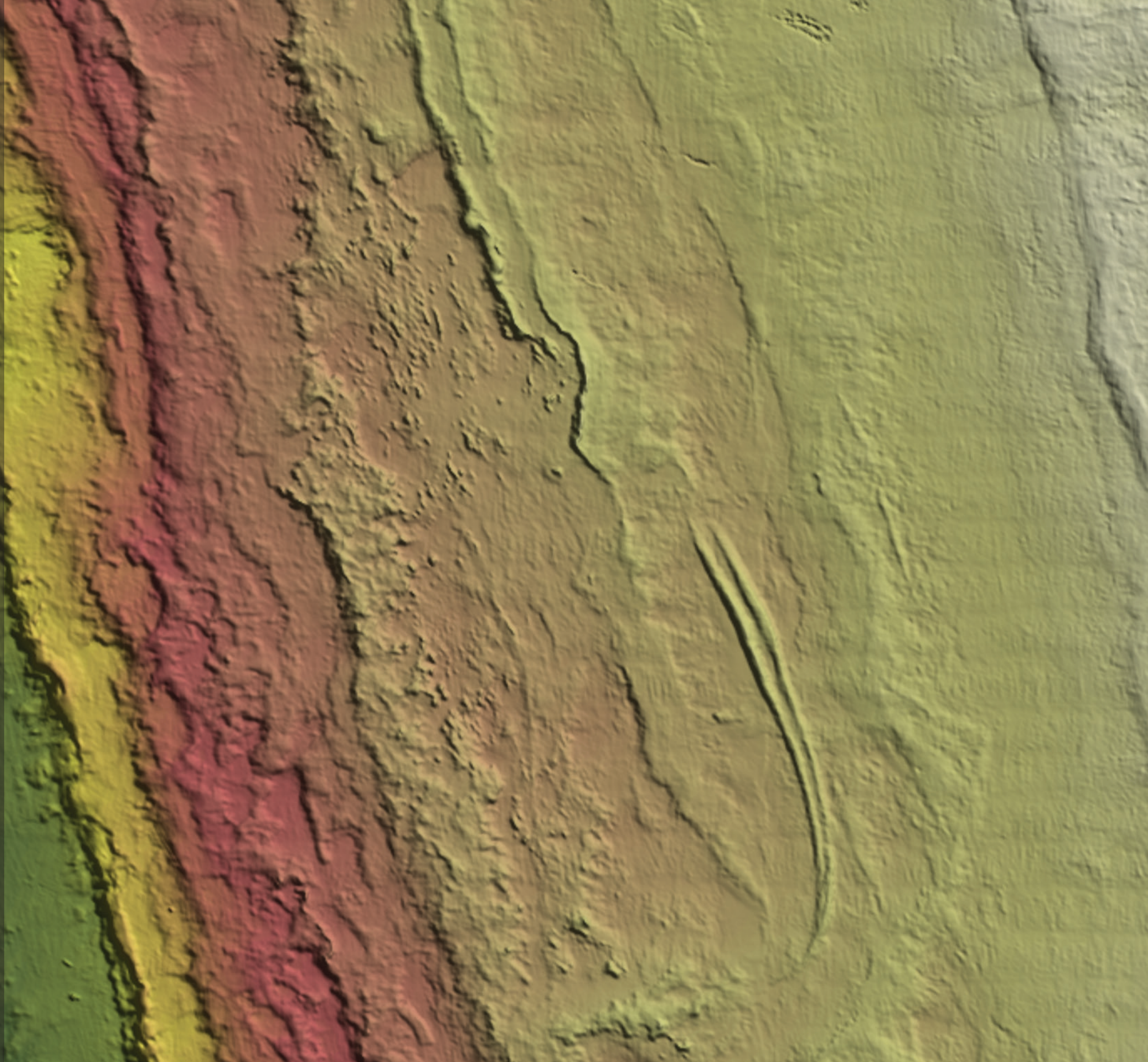
Dr Ilse Kiessling

Section 5 Intervening to restore coastal habitat

Before the Marine Biodiversity Hub, we were still in the dark about the value of many of our lesser known marine ecosystems and species. How did they function? What is their conservation status? Are they important to coastal communities and the blue economy? This incredible report highlights the wonderful work of our marine science community in revealing the importance of marine ecosystems and species to the Australian community. From Narrow Sawfish in the Northern Territory to Handfish in Tasmania and deep water rocky reefs to shallow-water oyster reefs, this wealth of new knowledge will enable all ocean stakeholders to better manage our oceans now and into the future.

Dr Chris Gillies

Australian Marine Parks



South-west Corner Marine Park bathymetry. Image: Geoscience Australia

Establishing ecological baselines to support adaptive management of Australian Marine Parks

The network of marine parks established in Australia's Commonwealth waters covers 3.5 million km² and is among the largest in the world.

Sixty Australian Marine Parks (AMPs) surround the continent, representing depths and habitats from shallow tropical coral reefs to deep seamounts and soft-sediment plains.

The parks play an important role in conserving marine life and supporting our livelihoods, recreational pursuits and overall wellbeing. They also help to protect cultural values significant to Aboriginal and Torres Strait Islander people.

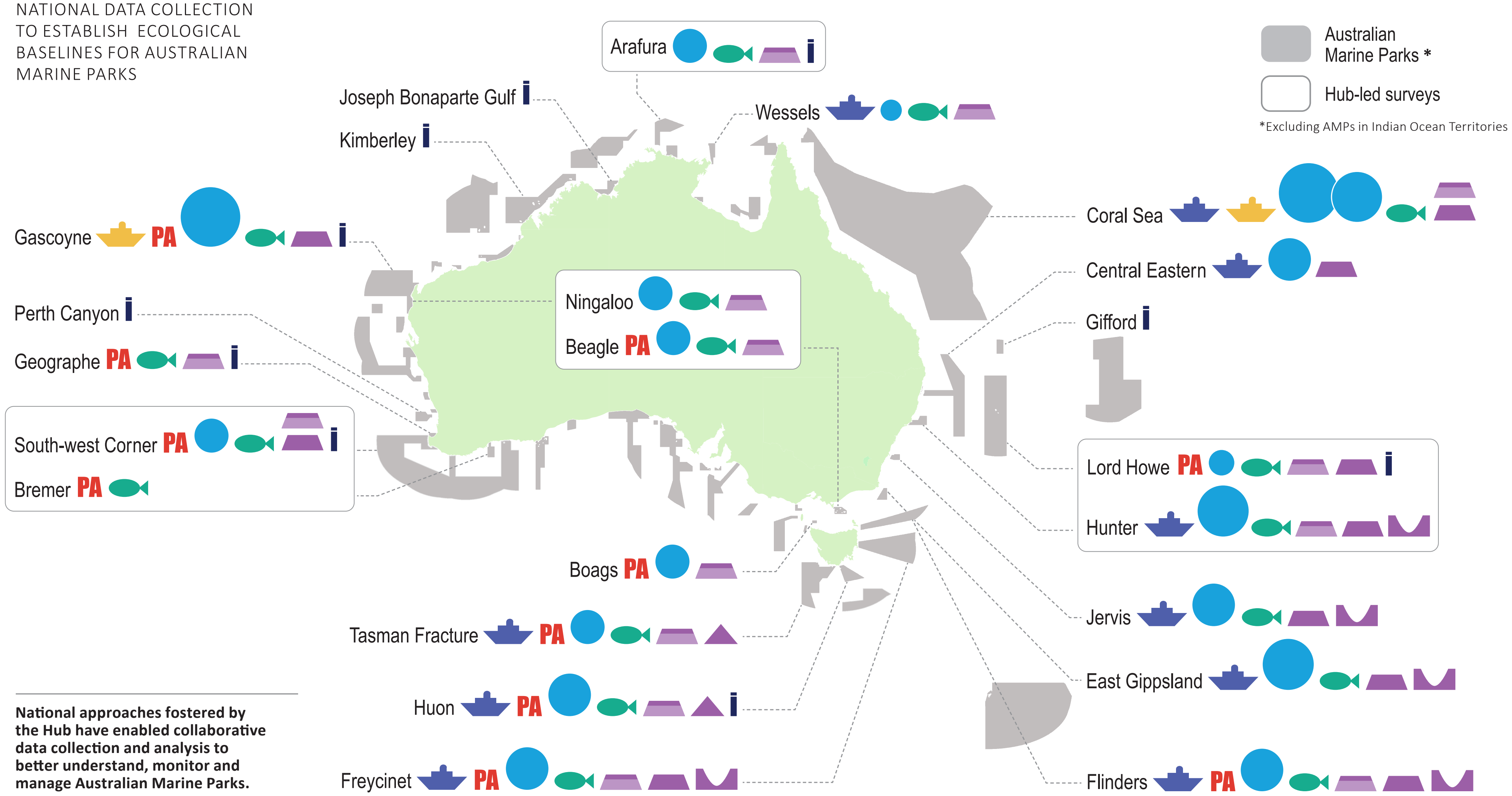
Parks Australia is developing a management effectiveness system to support the adaptive management of AMPs (see story on page 24). Hub research strengthened the evidence base required to establish and implement this system. Early Hub studies reviewed existing knowledge for AMPs, and recommended strategies for nationally consistent data collection and management. Subsequent work with Parks Australia identified survey locations and approaches to establish baselines for evaluating management effectiveness.

Surveys led and funded by the Hub and research partners were conducted in seven AMPs: Arafura in the north, Ningaloo in the west, South-west Corner and Bremer in the south-west, Beagle in the south-east and Hunter and Lord Howe in the temperate east. Hub researchers partnered in surveys of Boags, Freycinet, Huon, Tasman Fracture, Wessels and Gascoyne Marine Parks.

The Hub also supported a voyage to survey abyssal depths in Freycinet, Flinders, East Gippsland, Hunter, Central Eastern and Coral Sea Marine Parks. The AMP surveys acquired high-resolution seafloor maps and established baseline inventories of biological values, developed methods to predict habitat and biodiversity, and demonstrated cost-effective sampling platforms. Other projects created social and economic benchmarks for AMPs, and mapped activities and pressures nationally to identify risks. The new knowledge helped to identify monitoring priorities and key indicators of ecosystem values and pressures.

Throughout this work the Hub orchestrated new levels of collaboration – across agencies, and between researchers and research users – to build the national capacity required to meet the needs of managers. This involved coordinated use of national research infrastructure including the Integrated Marine Observing System, CSIRO Marine National Facility and Australian Ocean Data Network, and shared approaches to data collection, management, access and visualisation (see story on page 88).

NATIONAL DATA COLLECTION TO ESTABLISH ECOLOGICAL BASELINES FOR AUSTRALIAN MARINE PARKS



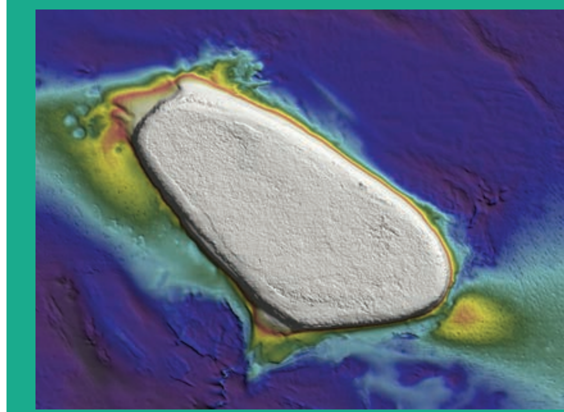
National approaches fostered by the Hub have enabled collaborative data collection and analysis to better understand, monitor and manage Australian Marine Parks.

Linking people, portals and platforms

National working groups supported by the Hub include the National Marine Science Committee Monitoring and Baselines Working Group, the annual Marine Protected Area Science/Management Forum, the Benthic Monitoring Autonomous Underwater Vehicle Working Group, and the Baited Remote Underwater Video Working Group. These networks championed national approaches, facilitated data sharing, and helped to catalyse the AusSeabed and Seamap Australia data portals.

BELOW: **Bathymetry mapping resulting from a Hub-funded survey at Money Shoal in Arafura Marine Park.**

BOTTOM: **A baited remote underwater stereo-video system on duty in Huon Marine Park.** Image: Institute for Marine and Antarctic Studies



Zooming in on rocky reefs

Before embarking on surveys in Australian Marine Parks (AMPs), Hub researchers collated and reviewed existing information on natural values to make useful knowledge accessible to managers, regulators and the public.

Rocky reefs and other habitats on the continental shelf were a key focus. Marine bioregional plans recognise rocky reefs as key ecological features that support seafloor and pelagic marine communities, including migratory species. They are prioritised in AMP management strategies, and can be subject to a range of pressures, including from fishing, shipping and climate change. The Hub studies highlighted how little is known about the extent and nature of rocky reefs beyond their value to commercial and recreational fishers, and identified priority areas for surveys. Apart from the Great Barrier Reef, and inner-shelf reefs of the Temperate East, South-east and South-west regions, few rocky reefs on Australia's continental shelf had been mapped in high-resolution. Human impacts and rates of recovery were virtually unknown, and the biodiversity and ecology of most reefs were undescribed.

The reefs have an ancient history. During the last ice age, sea level dropped to about 125 m lower than today, turning vast areas of Australia's continental shelf into land. This ancient continent, known as Sahul, was 20% larger than present-day Australia. Northern Australia joined to Papua New Guinea, the Gulf of Carpentaria was a salty lake, Darwin was 300 km from the coast, and people could walk across Bass Strait to Tasmania.

As sea level subsequently rose to cover the continental shelf, corals in tropical locations colonised limestone platforms such as lithified coastal dunes and other rocky surfaces on higher ground. Some of these sunlit coral reefs kept up with sea level rise, but the vertical growth of others stalled. These stalled reefs became mesophotic (middle light) reefs when sea level reached its present position about 6,500 years ago (see story on page 9). In many temperate locations these rocky areas and lithified coastal dunes also became mesophotic reefs and home to a diversity of invertebrates and fishes.

Honing the survey toolkit

In AMPs identified as priority areas for acquiring new knowledge, Hub surveys used a standard toolkit to map and sample seafloor features and biodiversity, and demonstrate effective, repeatable data collection and analysis.

Bathymetry is mapped in fine detail (~2–4 m spatial resolution) using multibeam sonar, revealing features such as rocky reefs to be surveyed using visual sampling tools. Autonomous underwater vehicles are flown along transects to video seafloor habitat, and baited remote underwater stereo-video systems placed on the seafloor record the comings and goings of fishes and other mobile marine life. Towed video, drop cameras, aircraft, sediment grabs, trawl nets, scuba divers and drones were also deployed on selected surveys.

The work continues with analysis of all the acoustic data and imagery. Invertebrates and fishes are identified where possible, measured and counted. Environmental variables such as depth and seafloor type are analysed in concert with the biodiversity records to identify relationships that allow habitat types to be predicted across broader expanses of the seafloor.

FURTHER INFORMATION

alan.jordan@utas.edu.au

Continental shelf biology and habitat descriptions for temperate AMPs

Collation of shelf reef mapping data and gap identification

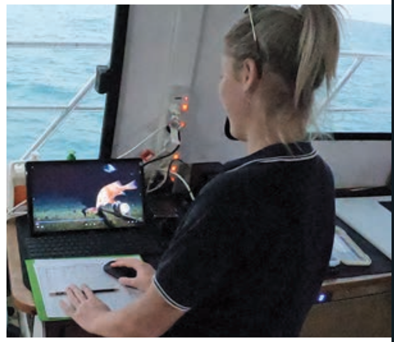
BELOW LEFT TO RIGHT:

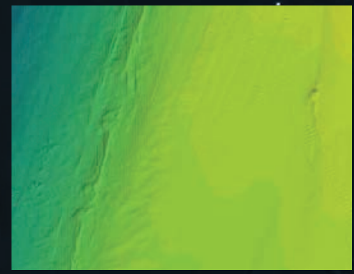
Acquiring seafloor imagery in Beagle Marine Park. Image: Geoscience Australia

Retrieving a stereo-BRUV in Lord Howe Marine Park. Image: Aero Leplastrier, Geoscience Australia

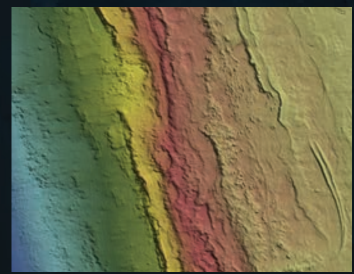
Deploying an autonomous underwater vehicle from the TV *Bluefin* in Lord Howe Marine Park. Image: Kristy Brown, IMAS

Acquiring stereo-BRUV imagery in Ningaloo Marine Park. Image: University of Western Australia





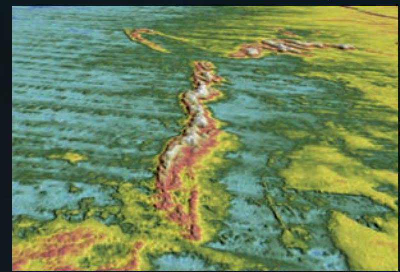
Linear features in the National Park Zone of Ningaloo Marine Park (Commonwealth waters) indicate an ancient shoreline.



Ancient shorelines mapped in South-west Corner Marine Park are thought to date back 12,000 and 18,000 years.

Sahul image: Damien O'Grady and Michael Bird, James Cook University

Inset images: Geoscience Australia



Mapping in Beagle Marine Park revealed the land bridge that once joined Victoria and Tasmania in north-eastern Bass Strait. Long narrow ridges on the former land bridge are the lithified remnants of sand dunes that formed during the drier and windier climate of the last ice age.

Some corals found at dim, mesophotic depths are wide and flat to catch more light. These corals live on the flank of a seamount at Elizabeth Reef in Lord Howe Marine Park. Mesophotic coral ecosystems here may provide refuge for coral and other seafloor and pelagic life in a warming ocean.

Tripping the light mesophotic

The shallow reefs enjoyed by snorkellers and scuba divers are just the tip of an extensive network of coral and rocky reefs that reaches deep into the ocean. This hidden realm was a prime destination for Hub researchers during surveys of Australian Marine Parks (AMPs). Using tools for mapping and collecting imagery in deep and remote waters, they opened a window on the largely unexplored world of mesophotic (middle light) reefs.

At depths of 30–70 m, mesophotic reefs can be remote from many of the stresses that affect inshore shallow reefs, such as coral bleaching, pollution, habitat loss and some forms of fishing. Because of this, they may serve as potential sources to reseed or replenish degraded shallow-water coral reef species. But mesophotic reefs are not remote from all human pressures.

Light-dependent species in this dim environment are particularly vulnerable to sedimentation, turbidity or pollution, and endemic species that are tied to a specific depth range or geographical location live on a knife edge of existence. Deep reefs across Australia's continental shelf are still subject to commercial fishing, and recreational fishers are visiting these areas as increased knowledge and technological improvements enable them to target deeper waters.

Light-dependent corals can live to depths of 150 m, and on mesophotic reefs in tropical and sub-tropical areas they live alongside macroalgae, sponges, and non-light-dependent species such as black corals and octocorals, creating places for fishes and other mobile species to spawn, shelter and feed. Mesophotic reefs in cooler, temperate waters are more likely to be dominated by a variety of sponges, ascidian and sea whips.

The Hub surveys made an important contribution to understanding mesophotic reef ecosystems in AMPs. They showed that the more we look for mesophotic reefs, the more we find. AMP managers now have high-resolution maps of selected reefs, baseline information about their structure, biology and condition, and a pathway to understanding the impacts of human activities.

The new information on mesophotic reefs is critical to making informed decisions about protecting and conserving mesophotic ecosystems. It will underpin conservation planning, zoning and other marine policy and adaptive management frameworks for AMPs. For example, mesophotic reefs have been recognised as key natural values as part of the management effectiveness system applied to the South-east Marine Parks Network (see story on page 24).

Unexpected for the Northern Territory: a rich coral community in crystal clear waters at Money Shoal. Image: AIMS

1

AUSTRALIAN MARINE PARKS

Arafura reefs abound with corals and fishes

Arafura Marine Park north-east of Darwin is one of eight Australian Marine Parks (AMPs) in the North Marine Parks Network. The park provides multiple benefits for Traditional Owners, regional communities and the Australian economy.

FURTHER INFORMATION

k.miller@aims.gov.au

Arafura survey report

The Yuwurrumu members of the Mandilarri-Ildugij, the Mangalara, the Murran, the Gadura-Minaga and the Ngaynjaharr clans have responsibilities for Sea Country in the marine park, which they have been sustainably using and managing for tens of thousands of years.

A Hub study that reviewed available knowledge for the North Marine Parks Network reported major gaps in understanding for most AMPs in this region. Parks Australia subsequently identified Arafura Marine Park as a priority for acquiring new knowledge. Of particular interest are the park's reefs and canyons, which are recognised as key ecological features. This survey applied the Hub's standardised methods of data collection to build a baseline inventory of reef habitats and adjacent soft sediment areas.

Survey and findings

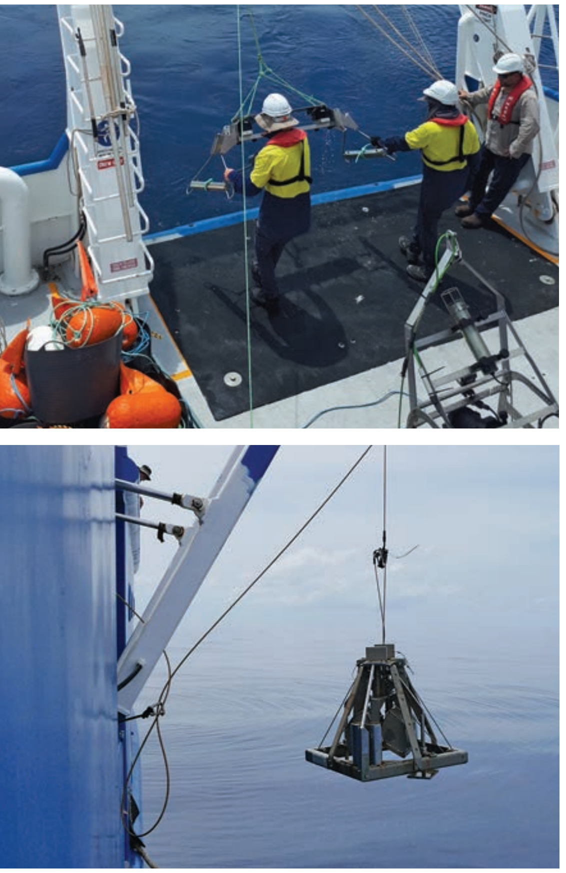
The Arafura Marine Park survey was undertaken by AIMS and Geoscience Australia in November 2020 on board RV *Solander.* The survey focused on deep and shallow pockets of reef amid the park's sediment plains. In the north of the park, at the outer edge of Australia's continental shelf, the survey team visited Pillar Bank (>120 m depth), part of an ancient river system that began its transformation to ocean some 14,000 years ago. In the shallower, southern area of the park, they visited Money Shoal, an oval shaped reef (3–70 m depths) about 200 km north-east of Darwin. High resolution multibeam bathymetry and backscatter data were collected to map both areas in detail, across a total area of approximately 350 km².

The seafloor mapping at Money Shoal covered an area of 192 km² incorporating the outer margins of the reef shoal and surrounding sediment plain. Sediment samples collected at 29 sites ranged from coarse carbonate sands on the reef margin and immediate surrounds, to mud (silt) on the deeper plain. Towed video imagery was collected along 33 transects and baited remote underwater stereo-video systems (stereo-BRUV) were deployed at 57 sites.

Preliminary observations from videos show that Money Shoal supports a diverse community of coral reef and demersal fishes that is unique within its regional setting. The shallow reef edge is dominated by medium to dense hard coral cover, although coral abundance declines with depth, with the intermediate shoal depths having a succession of habitats dominated by different animal and plant groups before the seafloor levels out to a relatively homogeneous muddy substrate surrounding the shoal in ~60 m water depth.

At Pillar Bank, seabed mapping covered an area of 160 km² across the bank and adjacent areas of plains, troughs, depressions and smaller banks and ridges. Sediment samples collected at 14 sites were dominantly mud, with localised deposits of carbonate sand and gravel on ridges and banks. Towed video was collected along 21 transects and stereo-BRUVs were deployed at 39 sites.

In contrast to Money Shoal, Pillar Bank is an extensive area of the park that supports sparsely distributed seafloor communities on hard substrate. Biological communities at the deeper Pillar Bank were depauperate compared with Money Shoal. Species observed included filter feeders (hydroids, gorgonians, sponges) as well as occasional mobile invertebrates such as echinoderms. Fish diversity was also low, with community composition varying predictably with substrate types, as is typical of typical of deeper waters in northern Australia.



ABOVE: **Launching a stereo-BRUV (upper) and sediment grab from RV *Solander.*** Images: AIMS.

ABOVE: **Rich shallow reef communities at Money Shoal with Grey Reef Sharks and Moorish Idol.** Images: AIMS

RIGHT: **Bathymetry (left) and backscatter maps of the Pillar Bank survey area, including sampling locations.** Image: Geoscience Australia

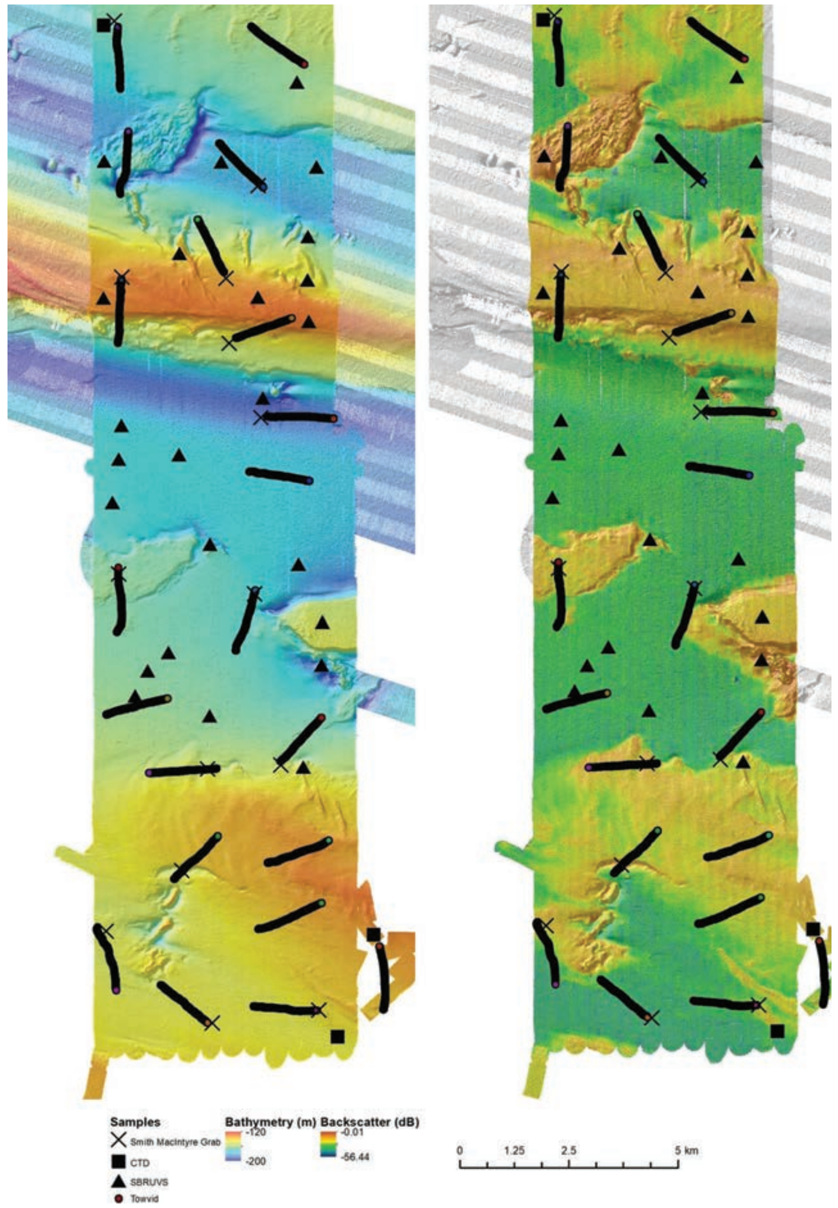
BOTTOM RIGHT: **Bathymetry and sampling locations at the Money Shoal survey area.** Image: Geoscience Australia.

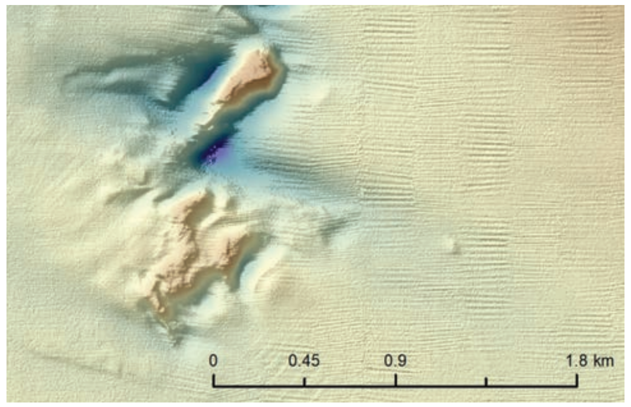
BOTTOM LEFT: **Ridges of hardground rising 40 m above the sediment plain at Pillar Bank.** Image: Geoscience Australia.

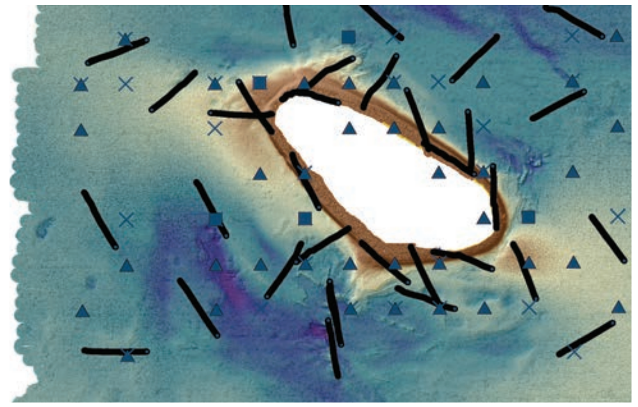
Outcomes and next steps

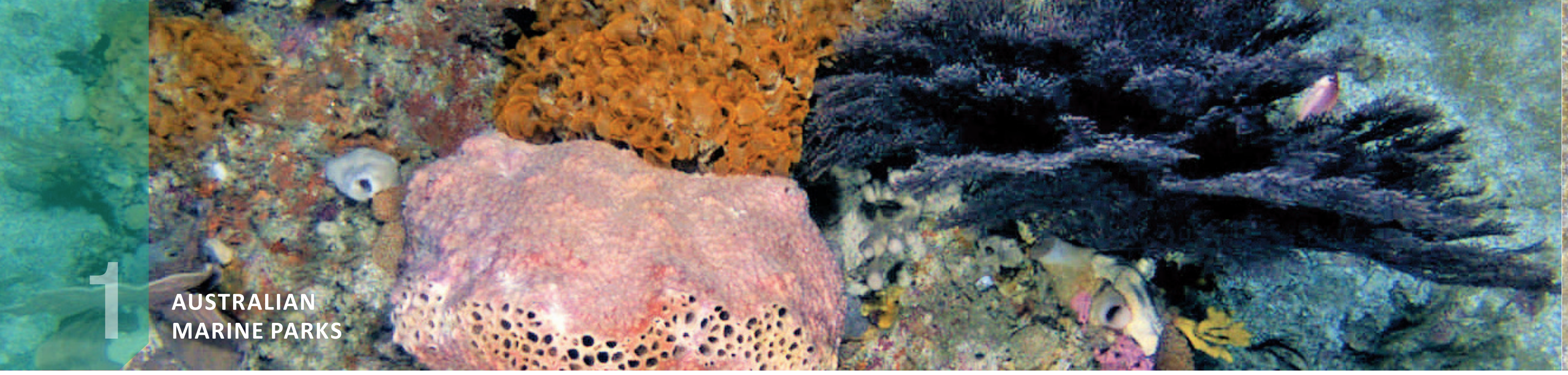
Detailed insights into the distribution of sediment and hardground habitat in Arafura Marine Park provided baseline information for monitoring and management. Newly documented features include extensive fields of small mounds on the margins of Money Shoal; pockmarks (deep depressions created by fluids escaping from beneath the seafloor) in sediments of the deeper plains; depressions formed by tidal scour; and isolated hard ridges.

Further analysis will determine relationships between environmental gradients (water depth and substrate type) and seafloor communities, and map species distribution and abundance across the two survey areas. In association with Parks Australia, the survey findings were shared with the Garngi ranger group on Croker Island. The Garngi manage the land and Sea Country adjacent to Arafura Marine Park.









Ahoy there, Beagle

Beagle Marine Park covers 3000 km² of continental shelf between Victoria's Wilson's Promontory and Tasmania's Flinders Island.

The park surrounds the state-managed Kent Group Marine Reserve (Erith, Dover, and Deal islands) and the Hogan and Curtis Island groups. These islands were once hills on the Bassian Plain, a landscape of dunes and grasslands that became immersed about 10,000 years ago by rising seas.

FURTHER INFORMATION
neville.barrett@utas.edu.au
Beagle survey report

The lithified dunes now form low-profile reefs 50–70 m below the surface, providing the foundation for much of the park's seafloor biodiversity. These mesophotic reefs are recognised by the Australian Government as a key ecological feature.

Survey and findings

In June 2018, a Hub team led by the University of Tasmania, Geoscience Australia and the University of Sydney Australian Centre for Field Robotics surveyed the submerged Bassian Plain, adding detail to formerly hazy maps of the seafloor. High-resolution acoustic mapping, sediment sampling and underwater imagery provided baseline information about the shape and structure of the seafloor, its habitats, and invertebrate and fish communities.

Samples of aeolianite (cemented dune sand) collected from the reefs dated back to the late Pleistocene (126,000–10,000 years ago), confirming the ancient dunes as having potential geoheritage value. The reefs may also hold cultural significance for Aboriginal peoples whose ancestors traversed this land bridge as far back as 30,000 years ago.

Today, the reefs provide a stable platform for attached invertebrates amid a broad carpet of shifting sediments. Sponges are dominant, with massive forms the most common, and creeping, encrusting, branching and cup sponges also recorded. Other attached invertebrates included cnidarians, bryozoans and ascidians. The park's former grassland plains host beds of doughboy scallops and New Zealand screw shells. In other areas clumps of rubble – shell hash, bryozoan skeletons, and scallops – provide further (perhaps ephemeral) hard surface for attached invertebrates.

Fishes were abundant in the park, with some 60 species recorded. Those most commonly seen were Degens Leatherjacket, Butterfly, Barber and Common Gurnard perches, Melbourne Silverbelly, Jackass Morwong, Rosy Wrasse, Cosmopolitan Leatherjacket, Sand Flathead and Draughtboard Shark.

Apart from Jackass Morwong and (rarer) flathead species, few commercially or recreationally targeted species were seen. Very few sharks were recorded, despite a significant shark fishery operating in the park in similar habitat targeted by the sampling.

A large group of Port Jackson Sharks was recorded near the reefs, raising the possibility that the adjacent scallop beds may provide a winter feeding ground for these sharks which lay their eggs off New South Wales in spring.

Outcomes and next steps

This survey generated new knowledge of the nature and extent of seafloor habitat and associated biological communities in Beagle Marine Park. Mesophotic reef habitats and communities emerged as important natural values, and the extent of the New Zealand screw shell was identified as a potential threat.

The new understanding and awareness allowed the identification priority locations for monitoring. Beagle's mesophotic rocky reefs and shelf unvegetated sediments were subsequently included as priority locations for monitoring in the South-east Marine Parks Network, as part of the Parks Australia management effectiveness system.

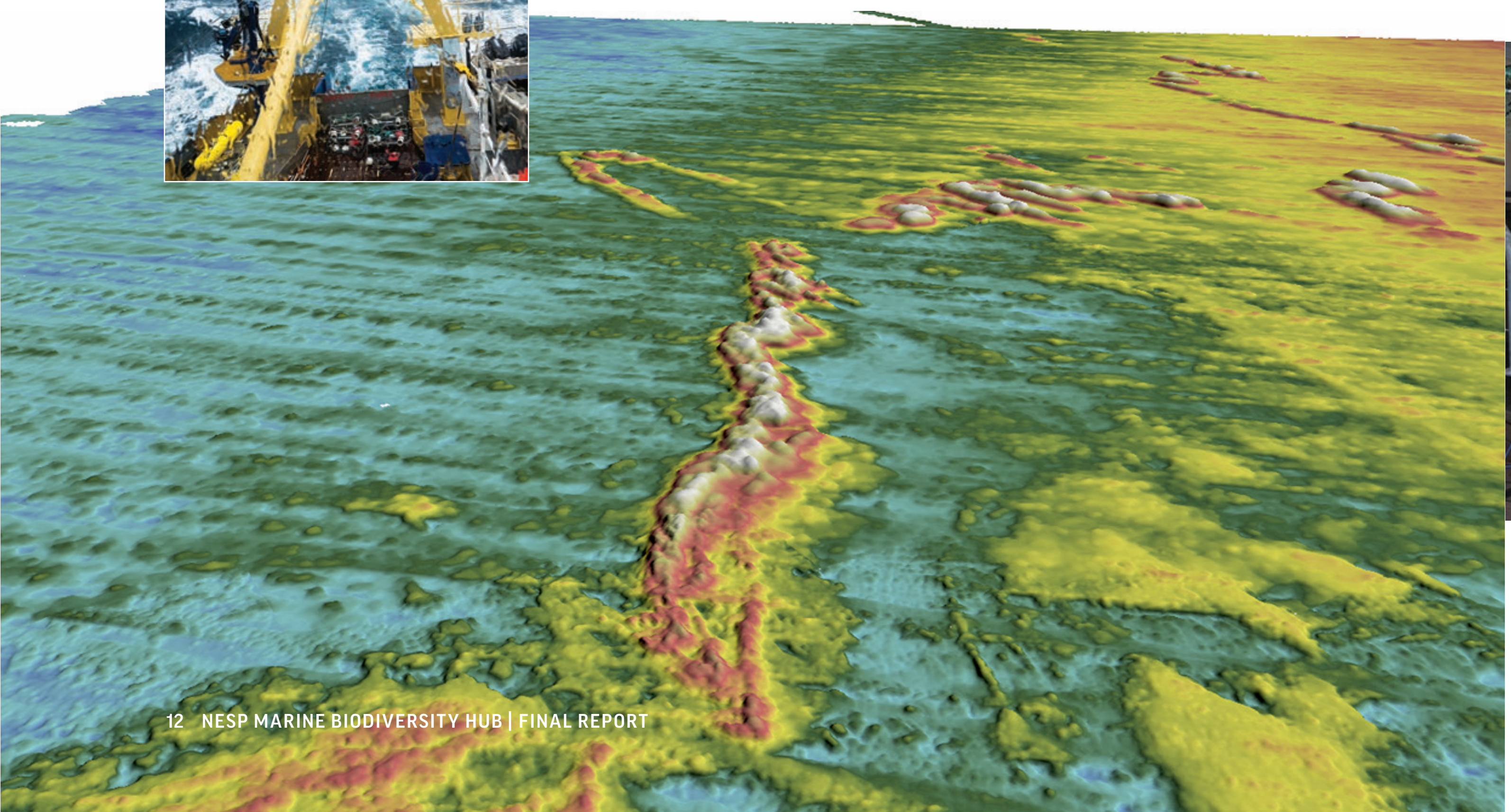
The survey also provided a direction for ongoing biological research and monitoring. Recommendations included:

- undertaking additional sampling to better estimate habitat and biodiversity coverage and clarify the geological stability of habitat for attached invertebrates;
- monitoring inside and outside the park to compare changes relevant to management effectiveness, and monitoring the burial and exposure of invertebrates attached to areas of rubble; and
- investigating why the survey observed low numbers of sharks, (apart from Port Jackson Sharks), and potentially shifting the monitoring focus to soft-sediment areas that support commercially targeted shark species.

TOP: **Diverse and colourful sponges on reef outcrops in Beagle Marine Park.** Image: IMAS/IMOS

LEFT: **The *Bluefin* met with rough weather in Bass Strait.** Image: Asher Flatt

BELOW: **High resolution mapping in Beagle Marine Park outlined the sharp, rocky ridges of ancient sand dunes that now provide habitat for dense sponge gardens and fish communities.** Image: Geoscience Australia



Doughboy scallops occupy the park's former grassland plains. Image: IMAS/IMOS

Part of a large group of Port Jackson sharks pictured by the autonomous underwater vehicle. Image: IMAS/IMOS

Justin Hulls of the Institute for Marine and Antarctic Studies, University of Tasmania and Lachlan Toohey of the University of Sydney Australian Centre for Field Robotics on the *Bluefin*. Image: Asher Flatt

Hub research leaders Scott Nichol of Geoscience Australia and Neville Barrett of the Institute for Marine and Antarctic Studies, University of Tasmania. Image: Asher Flatt

Christian Lees led the University of Sydney Australian Centre for Field Robotics team that deployed the *Sirius* autonomous underwater vehicle on multiple Hub surveys. Image: Asher Flatt

1

AUSTRALIAN
MARINE PARKS

Fishes loom large at Hunter's deep rocky reefs

Hunter Marine Park adjoins the state-managed Port Stephens-Great Lakes Marine Park off the New South Wales mid-north coast and is a popular destination for tourism and fishing.

The park has two management zones: a Special Purpose Zone (Trawl) on the continental shelf and upper continental slope to depths of 200 m, and a Habitat Protection Zone crossing the continental slope and canyons to abyssal depths.

Before this study, seafloor mapping and biological surveys had focussed in shallower waters of the state-managed marine park. While rocky reefs on the continental shelf of Hunter Marine Park are identified as a key ecological feature, their locations, habitats and fish communities were little known.

Baseline information was needed to better understand the park's natural values and assess changes through time. Of particular interest were rocky reefs in 80–120 m depths, which are fished by several commercial fishery sectors, and increasingly by recreational fishers. This study conducted the first high-resolution mapping and biological surveys of Hunter Marine Park.

Survey and findings

Surveys led by the New South Wales Department of Primary Industries from 2015 to 2020 covered three areas of Hunter Marine Park's special purpose zone: east of Broughton Island (80–110 m depths), Seal Rocks (80–105 m) and Outer Gibber (35–60 m). Multibeam echo sounder data were collected to map 125 km² of the seafloor in high resolution. Towed video transects in selected areas provided imagery to ground-truth the acoustic data and identify habitat features. Some 5.5 km² of mid-light and low-light rocky reefs emerged amid expanses of soft sediments. In deeper areas the reefs were generally low-profile and patchy. Long, linear ridges in deeper water off Seal Rocks are potentially associated with relict coastline.

Seafloor invertebrate communities at Outer Gibber's upper depths were dominated by branching and turfing brown algae, with encrusting and branching sponges, ascidians and sea whips. Deeper reef communities were dominated by branching sponges, non-light-dependent corals and sea whips, with symbiotic brittle stars. The soft sediments were dominated by infaunal burrows. Erect invertebrates (worm tubes) were almost always present at Seal Rocks, but less common at Broughton Island.

Fishes were abundant in the park, with a total of 113 fish species recorded by the baited remote underwater stereo-video (stereo-BRUV) deployments. Outer Gibber had the highest numbers of species recorded by a single stereo BRUV drop (28), probably because this reef is relatively shallow and has high-relief. Yellowtail Scad, Australian Mado and Redfish were the most abundant and ubiquitous species.

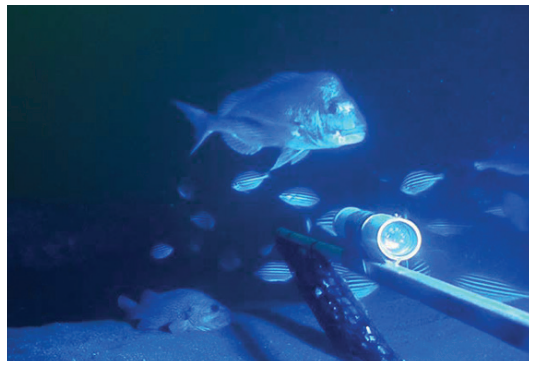
The lower reefs (>80 m) were dominated by Redfish, Reef Ocean Perch and Velvet Leatherjacket. Most notably, several species popular with recreational and commercial fishers were recorded in higher numbers at these depths, particularly Pink Snapper and Blue Morwong. Key fishery species weren't necessarily more abundant, but were larger in Hunter Marine Park than in the adjoining state park. Two threatened species – White Shark and Grey Nurse Shark – were also seen.

BELOW: **Fishes recorded by stereo-BRUV on reefs at 80–100 m depths at Seal Rocks Offshore in Hunter Marine Park.**

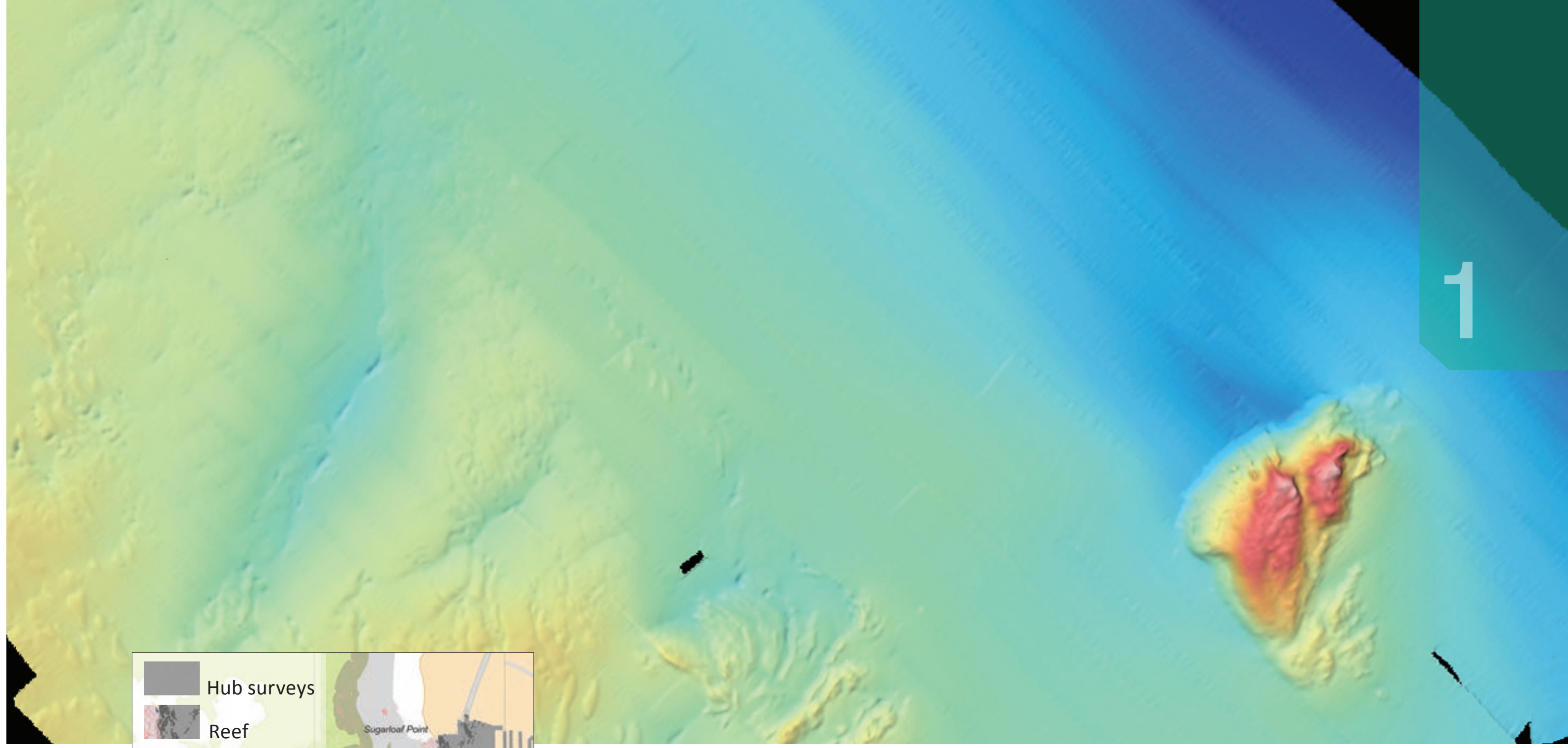
LEFT: **A Teraglin swims above diverse invertebrate habitat.**

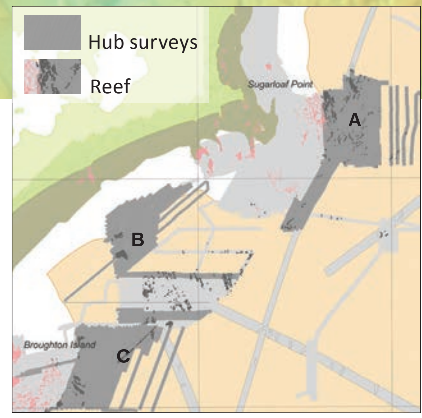
CENTRE: **A newly born 1.8 m white shark smiles for the camera.**

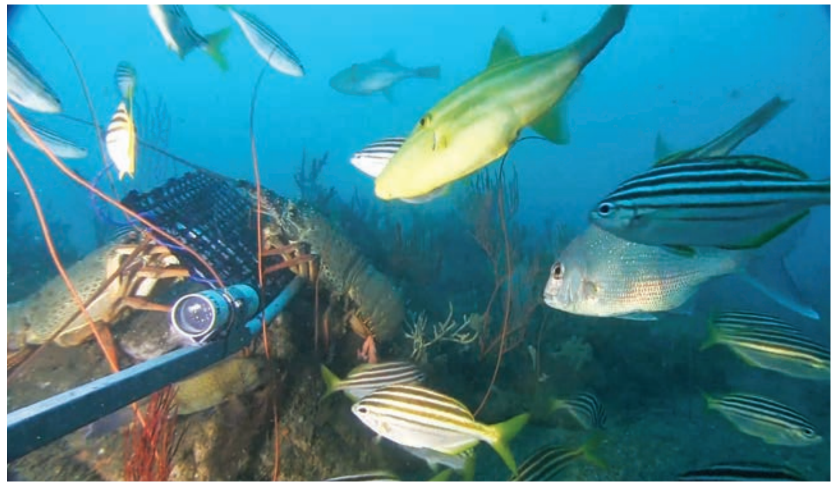
RIGHT: **A large pink snapper. Key fishery species were larger in Hunter Marine Park than in the adjoining state park.** Images: New South Wales Department of Primary Industries



1







ABOVE: **The three survey sites in Hunter Marine Park. A: Seal Rocks, B: Outer Gibber and C: east of Broughton Island.**

TOP: **High-resolution seafloor mapping clarified the contours of rocky reefs such as Outer Gibber.**

ABOVE RIGHT: **Fishes at Outer Gibber. Red Morwong, Old Wives and Stripey aggregated in large schools on this high-relief reef.**

RIGHT: **A mesophotic reef at which Eastern Rock Lobster, Pink Snapper, Australian Mado and Ocean Leatherjackets were regularly seen.** Images: New South Wales Department of Primary Industries

Outcomes and next steps

This study provided the first maps outlining the extent of shelf rocky reef, which is an identified key ecological feature of Hunter Marine Park. Park managers were provided with baseline data essential to designing a monitoring program for invertebrate and fish assemblages, and identifying areas where activities such as fishing may act as a pressure on park values.

The new understanding will allow Parks Australia to identify priority locations for monitoring as it extends its management effectiveness program to Marine Park Networks around Australia.

The study also identified priority areas for additional baseline data collection in areas subject to fishing, and recommended gaining a better understanding of the East Australian Current and environmental variables governing year-to-year variability. This is particularly important for assessing the impacts of climate change. Spectacular imagery captured during this research helped to showcase and raise awareness about the rich natural values in this location.

FURTHER INFORMATION
joel.williams@utas.edu.au
Hunter survey report

Exploring refuge at our southern-most coral reefs

Black corals at a depth of 46 m on the shelf of Elizabeth Reef. Images: Geoscience Australia

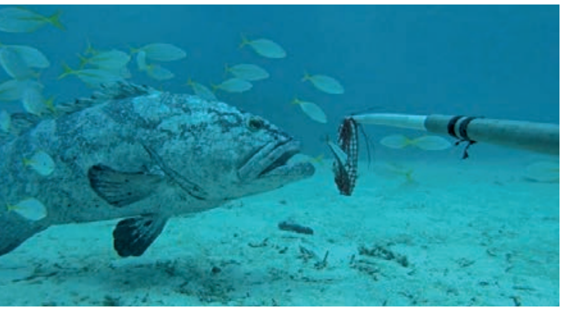
Elizabeth and Middleton Reefs are atoll-like structures associated with the Lord Howe seamount chain.

The reefs lie in Lord Howe Marine Park, and host a unique collection of tropical, subtropical and temperate marine life. They are recognised by the Australian Government as a key ecological feature, and globally as a Ramsar Wetland, so require a management framework to ensure their conservation and wise use.

FURTHER INFORMATION

andrew.carroll@ga.gov.au

Elizabeth and Middleton reefs survey report



ABOVE: **A Black Cod in Middleton Reef lagoon; The reefs are a stronghold for immature Galapagos Sharks.** Images: Geoscience Australia

While the reefs' shallow lagoons and inner shelf waters had been surveyed by divers, the deeper shelf environments surrounding the reefs were relatively unknown. Information on the distribution, extent and structure of seabed habitats and communities at different depths was needed to support monitoring and management by Parks Australia.

There is also global interest in studying the connections between shallow and deeper reefs, particularly those at the latitudinal limits to reef formation. The mid-light coral ecosystems on the sub-tropical shelves of Balls Pyramid and Lord Howe Island have the potential to act as a refuge for shallow-reef species under a changing climate. Relatively little was known about the shelf environments of Elizabeth and Middleton Reefs.

Survey and findings

The February 2020 survey to Elizabeth and Middleton Reefs led by Geoscience Australia used multibeam sonar to map shelf environments of each seamount in high spatial resolution. The mapping revealed the underlying geomorphology (seafloor structure) that influences patterns of biodiversity. Invertebrate and fish communities were visually sampled with autonomous underwater vehicles (AUVs) and baited remote underwater stereo-video (stereo-BRUV). For Middleton Reef, survey work was completed for the entire shelf. Elizabeth Reef shelf remains partially mapped and sampled, as survey activities were curtailed by weather conditions associated with ex-tropical cyclone Uesi. However, the mapped areas of both shelves appear similar.

The gently sloping shelf platform of each reef has a complex seafloor characterised by mounds, ridges, planes and depressions. Mound, ridges and planes on the inner shelf (20–50 m depths) were dominated by turfing macroalgae, cnidarian corals (hard reef-building corals and soft leather corals) and bacterial mats. Black corals, branching and whip corals dominated planes and ridges on the outer shelf (70–110 m), among areas of coarse carbonate sand, turfing algae, hard corals, sponges and calcareous rhodoliths beds. These results are similar to seafloor habitats described on the shelves surrounding Lord Howe Island and Balls Pyramid, where communities vary among inner, mid and outer-shelf areas.

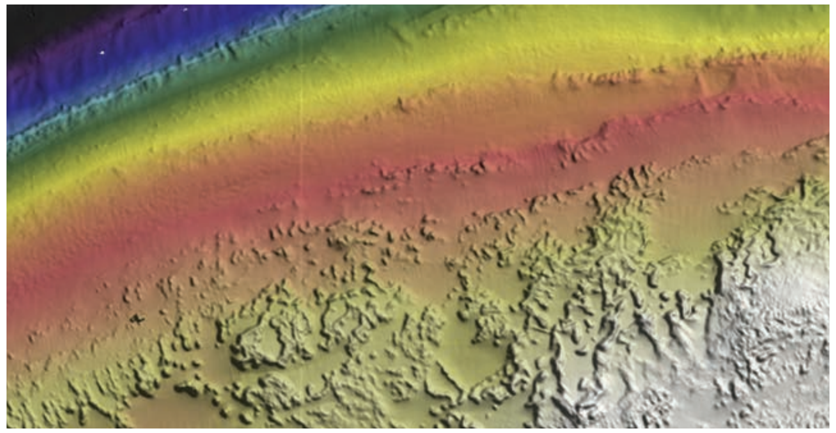
Bottom-dwelling fish were abundant and diverse across lagoon, inner shelf and deeper shelf habitats, with nearly 200 species recorded. Clear patterns in some trophic feeding guilds were evident across depths at both reefs. While scraping and browsing herbivore abundance decreased with depth, generalist carnivore abundance increased with depth.

Whether due to protection or isolation, or a combination of both, the reef systems surveyed here had a large proportion of top predators relative to continental shelf waters off eastern Australia. Elizabeth and Middleton Reefs remain a stronghold for populations of predatory fish and listed threatened species, including mature Black Cod and Tiger Sharks, and immature Galapagos Sharks.

RIGHT: **Diverse sponge habitat under surveillance by the baited remote underwater stereo-video.**

LOWER RIGHT: **Bathymetry acquired at Middleton Reef showing the underlying seafloor structure that influences patterns of biodiversity.**

BOTTOM RIGHT: **Survey partners and collaborators from Parks Australia, University of Tasmania (Institute for Marine and Antarctic Studies and Australian Maritime College), Geoscience Australia, New South Wales Department of Primary Industries and the University of Sydney Australian Centre for Field Robotics (Integrated Marine Observing System Autonomous Underwater Vehicle Facility).** Images: Geoscience Australia.



Despite being limited by the truncated stereo-BRUV survey at Elizabeth Reef, initial survey results suggest a greater number of larger predators at the fully protected Middleton Reef than at Elizabeth Reef, which is open to fishing. Further sampling is required to determine whether this is a natural spatial pattern or one likely related to the extent of protection.

Outcomes and next steps

This is the first study to document deeper ecosystems on the shelf platforms of Elizabeth and Middleton Reefs. It demonstrated the utility of national standard tools such as AUVs and stereo-BRUV to sample areas not readily accessible to divers, and the value of using the Hub's best-practice survey design and sampling methods to ensure the comparability of survey data.

Quantitative baselines have been established to support the monitoring of natural values and pressures at a range of depths. This contributes to the management of Lord Howe Marine Park and the *Temperate East Marine Parks Network Management Plan 2018*. The new knowledge also improved understanding of the representativeness of a key ecological feature in the AMP.

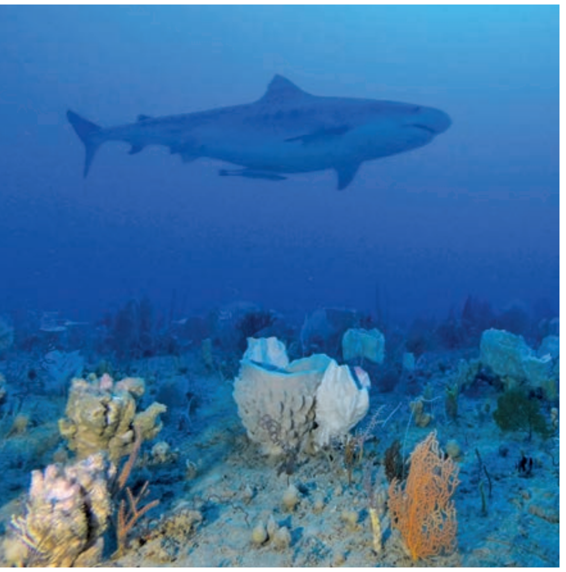
Recommendations for future research include:

- completing survey work at Elizabeth Reef to facilitate comparisons between management zones of the Lord Howe Marine Park;
- mapping and characterising deeper water habitats around each seamount reef to explore connectivity between shallow and deeper seafloor habitats;
- repeat-sampling of invertebrates and fishes at each reef to examine changes through time in the context of management goals;
- using satellite derived bathymetry to map the geomorphology of shallower lagoon and inner shelf areas; and
- conducting further stereo-BRUV surveys of fish communities to obtain population size estimates of key species such as Black Cod.

Dropping in on Ningaloo's deeper treasures

The offshore Ningaloo Marine Park (Commonwealth waters) adjoins the inshore, state-managed Ningaloo Marine Park. The two parks run parallel to the Western Australian coast for some 300 km, from Exmouth to south of Coral Bay, embracing Ningaloo Reef.

The Commonwealth park makes up 40% of the Ningaloo Coast World Heritage Area. While the shallow coral reefs of Ningaloo (Nyinggulu) Coast have been well researched, the deeper areas are relatively little known.



TOP: **Hub research leader Tim Langlois of The University of Western Australia all set to deploy a stereo-BRUV during the Ningaloo survey.**

ABOVE: **This Tiger Shark, possibly pregnant, was recorded in the newly established no-take National Park Zone.** Images: The University of Western Australia

Ningaloo Marine Park (Commonwealth waters) is one of the few Australian Marine Parks accessed by large numbers of recreational fishers. A National Park Zone declared in 2018 prohibited fishing in the mid-section of the park near Point Cloates. A survey of fish composition and abundance was needed to enable future monitoring of fish populations across the different management zones. This is necessary to assess changes that may occur in the National Park Zone, and the overall effects of recreational fishing on targeted species.

Survey and findings

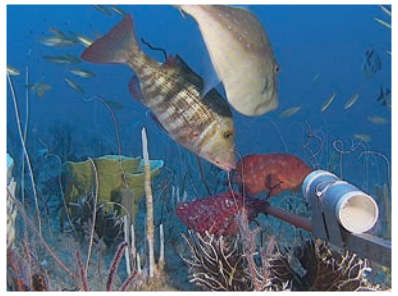
Two dedicated voyages were undertaken at locations west and south of Point Cloates. The first was led by CSIRO and the second was led by The University of Western Australia. The first survey in March 2019 collected acoustic (bathymetry and backscatter) data and towed video imagery of deep-water habitats in the new National Park Zone. The second survey in August 2019 deployed baited remote underwater stereo-video (stereo-BRUV) to visually sample fish near the seafloor. Additional acoustic data were acquired in 2017 on a CSIRO RV *Investigator* transect along the 125 m depth contour of the park, near what is thought to be an ancient shoreline key ecological feature.

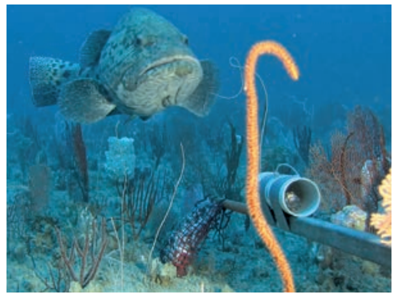
The acoustic data and towed imagery were used to classify habitat types according to seafloor hardness, roughness and depth. This classification contributed to the stereo-BRUV survey design, allowing seafloor features to be considered as a possible influence on fish distributions.

The survey area in the north of the National Park Zone was 68–272 m in depth, with linear seafloor features evident at two depths. Seabed features that aligned parallel with the 80–90 m contour indicated a possible ancient shoreline. They rose to 2 m above the neighbouring seafloor and were dominated by sparse to medium density sponge gardens with gorgonians and whips. Bedforms up to 4 m high ran perpendicular to the 185 m contour, again featuring sponge, whip, and gorgonian habitats. In the south of the National Park Zone, depth varied from 54–78 m, with mostly soft sediment habitats inhabited by burrowing animals. A larger feature to the south-eastern edge indicated a possible reef system.

The stereo-BRUV sampling was spread from the relatively remote National Park Zone in the south, to areas near recreational fishing access points in the north. Similar depth and habitat were sampled to ensure comparable fish communities. This included the state-managed Ningaloo Marine Park, and Gascoyne Marine Park. Historical sites were also visited for comparison with initial surveys conducted 10 years ago.

BRUVs were deployed at 133 sites in 55–190 m depths, recording 169 fish species near the seafloor. The 10 most abundant species were: Mackerel Scad, Goldband Snapper, Robinson's Sea Bream, Redthroat Emperor, Longnose Trevally, Frypan Bream, Bludger Trevally, Spotcheek Emperor, Yellowband Fusilier and Yellowspotted Rockcod. Goldband Snapper was the only species abundant enough to be analysed on its own, and this provided a sound baseline for future monitoring. Goldband Snapper abundance increased with water depth, but did not differ across gradients in estimated recreational fishing effort or inside or outside the National Park Zone.





ABOVE**: The stereo-BRUV sampling recorded 169 fish species cruising in the sponge, sea whip and gorgonian habitats.**

TOP TO BOTTOM: **Redthroat Emperor and Unicorn Leatherjacket.**

A Potato Rockcod heading for a sea whip.

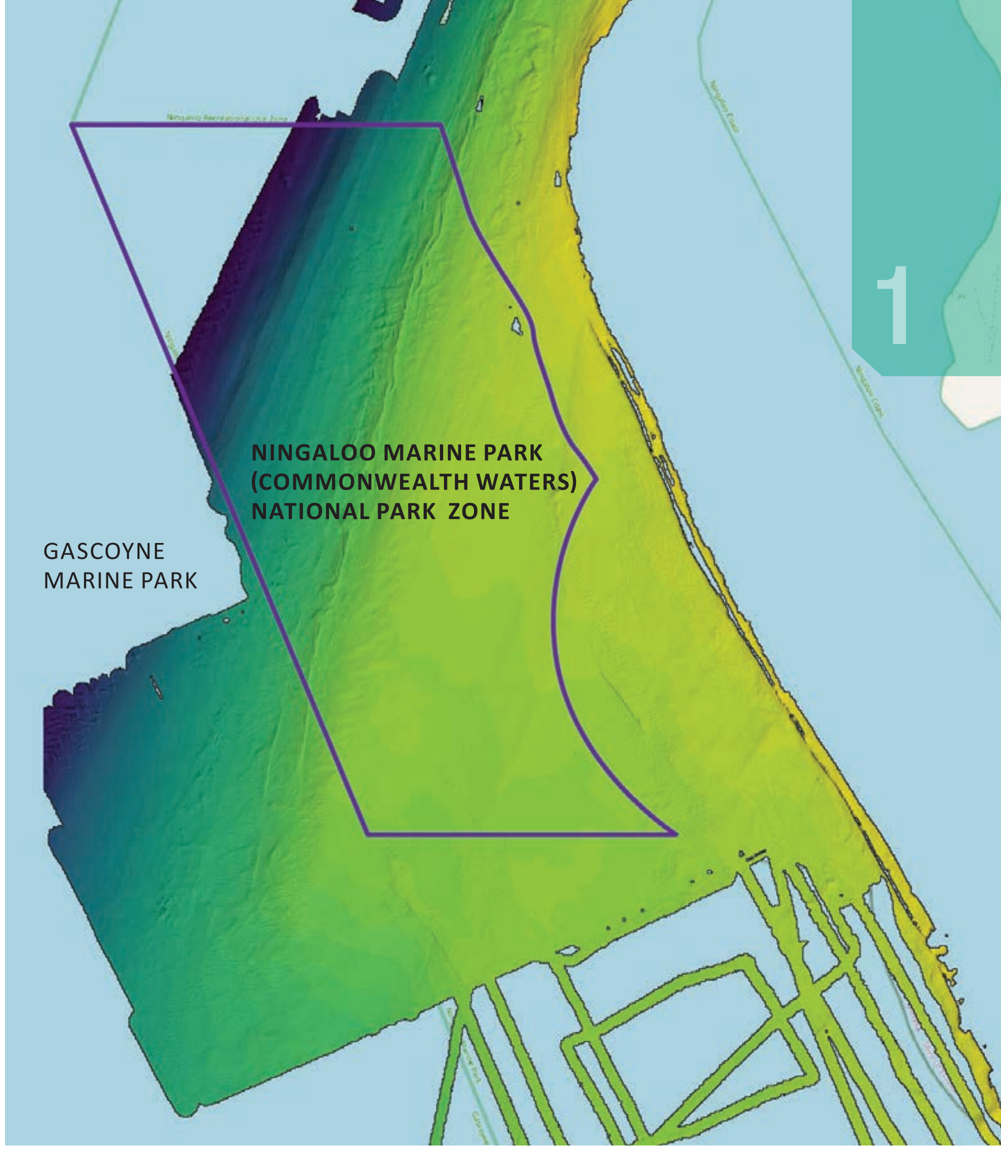
Goldband Snapper abundance increased with water depth, but did not differ across estimated recreational fishing effort, or in the National Park Zone.

A Comet Grouper recorded at a depth of 145 m. Images: The University of Western Australia

FURTHER INFORMATION

john.keesing@csiro.au

Ningaloo survey report



High resolution mapping in the National Park Zone of Ningaloo Marine Park (Commonwealth Waters) revealed ancient shorelines at various depths, and reef systems likely to provide fish habitat. Image: CSIRO

Recreationally targeted fish were analysed as one group. Those greater than legal size were more abundant with increasing depth and lower estimated recreational fishing effort. As with Goldband Snapper, their abundance did not differ significantly in the National Park Zone compared with sites in the Recreational Use Zone or General Use Zone of comparable depth and habitat. Over time, the abundance of fished species is expected to increase in the National Park Zone, providing a benchmark for understanding conservation and management success across the broader AMPs.

Outcomes and next steps

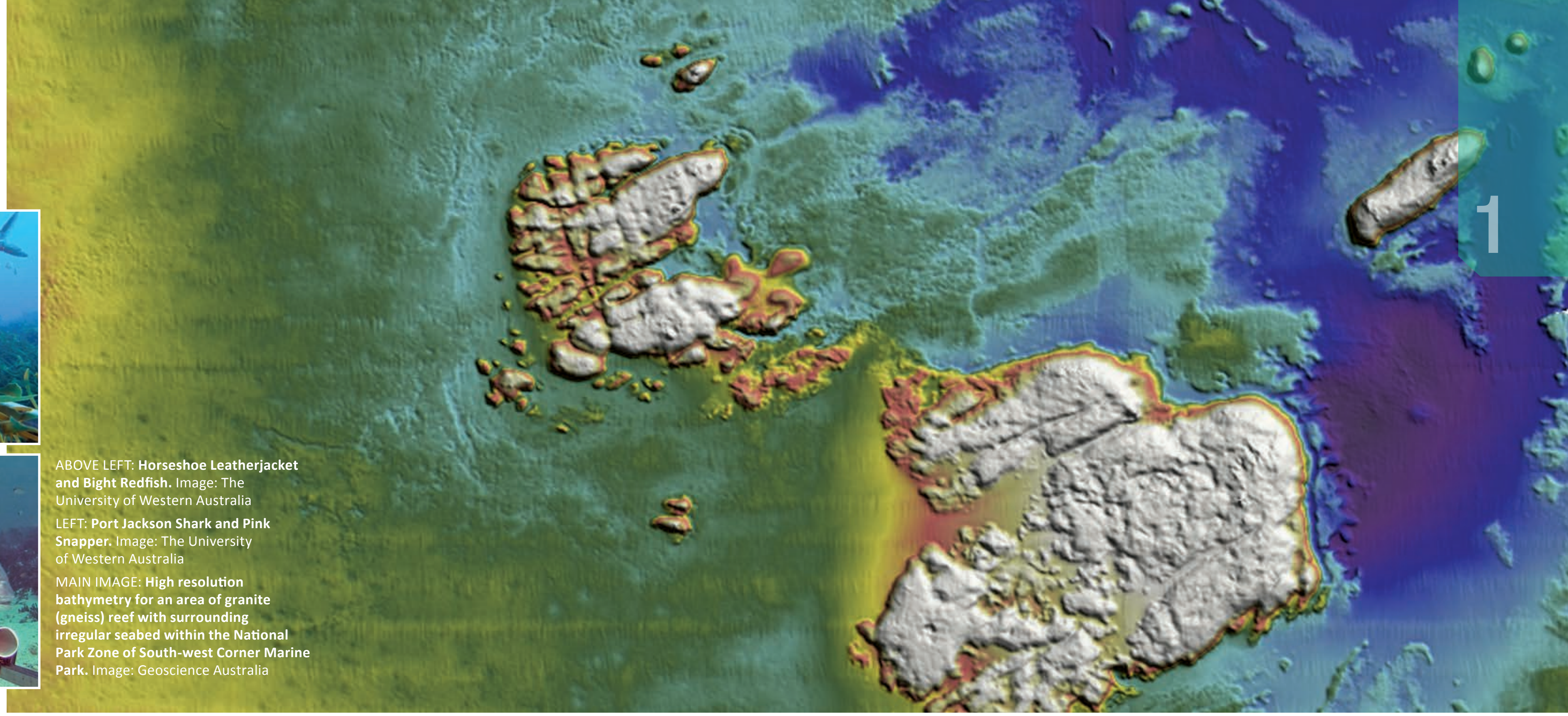
This study extended the spatial coverage of habitat maps and provided a baseline for monitoring the abundance of species targeted by recreational fishers in Ningaloo Marine Park (Commonwealth waters). Findings regarding the importance of No Take zones and the increased abundance of targeted fish with increasing distance from boat ramps are also relevant to species that co-occur in the adjacent state park. Comparisons between fished and unfished areas should be continued, given this study has provided a baseline near to the time of establishment of the National Park Zone.

The finding that the abundance of at least one species, Goldband Snapper, can change significantly between periods of assessment (in this case 10 years) highlighted the need for at least three-yearly repeat surveys. Greater sampling effort is also recommended. This is because despite the sampling effort undertaken (130 BRUVs drops) for most species, there was insufficient data for individual species assessments (except Goldband Snapper). Lastly, the study reinforced the importance of a robust, premeditated statistical design to avoid biases in sampling over time.

Surprising South-west Corner

South-west Corner Marine Park is the largest of 14 Australian Marine Parks in the South-west Marine Parks Network. It covers an area larger than Victoria, in offshore waters from Cape Naturaliste to Esperance.

The park embraces reefs and banks on the continental shelf, submarine canyons, Naturaliste Plateau, and the abyssal Diamantina Fracture Zone. It hosts whales, sharks and sea lions, and provides valuable habitat for western and southern rock lobsters. Recreational activities include diving, snorkelling, nature-watching and fishing.



ABOVE LEFT: **Horseshoe Leatherjacket and Bight Redfish.** Image: The University of Western Australia

LEFT: **Port Jackson Shark and Pink Snapper.** Image: The University of Western Australia

MAIN IMAGE: **High resolution bathymetry for an area of granite (gneiss) reef with surrounding irregular seabed within the National Park Zone of South-west Corner Marine Park.** Image: Geoscience Australia

Seafloor habitat pictured by the autonomous underwater vehicle. Images: The University of Western Australia

Knowledge of natural values is vital to support management of South-west Corner Marine Park, but only 6% of the park's continental shelf had been mapped before this study. High-resolution bathymetry and visual sampling was needed to build a baseline inventory of key seafloor habitats and fish assemblages.

A Hub team led by The University of Western Australia and Geoscience Australia mapped and sampled shelf habitats in one of the park's National Park Zones and adjacent Special Purpose Zone (Mining Exclusion), west of Cape Mentelle and Cape Freycinet. Cultural mapping and frequent communication with Traditional Owners allowed for the consideration of traditional ecological and scientific knowledge in the planning, collection and interpretation of biodiversity data (see story on page 51).

Survey and findings

Due to interruptions caused by the COVID 19 pandemic, the survey occurred in six stages, between March 2020 and March 2021. Acoustic data were collected for seafloor mapping across 330 km² of the National Park Zone and adjacent Special Purpose Zone, between the eastern boundary of the park and the shelf break. Baited remote underwater stereo-video (stereo-BRUV), a drop camera, and an autonomous underwater vehicle (AUV) were used for visual sampling.

While all the data are yet to be processed, an initial picture of patterns in seafloor habitats and fish communities is starting to emerge. Several small isolated high-profile reefs exist at ~30–50 m depths in the south-east of the National Park Zone. The majority of mid-shelf habitat consists of flat pavement reefs interspersed with sand sediments. Both reef types support diverse communities of macroalgae, seagrass, hard corals and sponges. Further offshore, deeper ledge features, orientated in a north-south direction at depths of ~120 and 200 m, support diverse filter feeding communities dominated by hard bryozoans, hydroids, black and octocorals, and sponges. At the shelf break in 200 m the sparsely inhabited silty mud sediments supported aggregations of Hapuka, a large deep-water groper.

Seafloor mapping in 60 m depth revealed linear to curved ridges rising 2–3 m above the flat pavement area range from <100 m to 500 m in length and are approximately 20 m wide. These are likely to be relict coastal dunes preserved as lithified aeolianite that lined an ancient coastline dating back some 12,000 years. Further out in 120 m depth, the distinct shorelines from the last glacial maxima about 18,000 years ago can be seen.

The stereo-BRUV deployments recorded nearly 14,000 individual fish from 140 species and 61 families. The total abundance and species richness of seafloor fish assemblages showed marked changes with depth and was characterised by species typical of the region, including Western King Wrasse, Southern Maori Wrasse and Redband Wrasse. Pink Snapper were among the recreationally targeted species recorded, and aggregations of large-bodies Hapuka Grouper were observed on the shelf break in 200 m. Five observed species – Sandbar Shark, Western Blue Groper, Bigeye Tuna, Smooth Hammerhead and School Shark – are listed as vulnerable by the International Union for Conservation of Nature.

A potential Grey Nurse Shark aggregation site was discovered in the National Park Zone, with five individuals recorded in one place at a depth of 137 m. If confirmed, this would be the second aggregation site known for Western Australia and the deepest known aggregation site for this species.

Outcomes and next steps

This survey demonstrated the effective collection of multiple extensive datasets according to national standards prescribed in the Hub's *Field Manuals for Marine Sampling to Monitor Australian Waters*. Additional work is needed to complete the annotation and analysis of survey data. This will establish a monitoring baseline for the survey areas, and help to identify key natural values and develop potential indicators and measures for reporting. These are integral to the development of an effective monitoring system for the South-west Marine Parks Network. The identification of a potential Grey Nurse Shark aggregation may be important to the conservation of this threatened species. Repeat surveys are needed to confirm how this site is used.

FURTHER INFORMATION

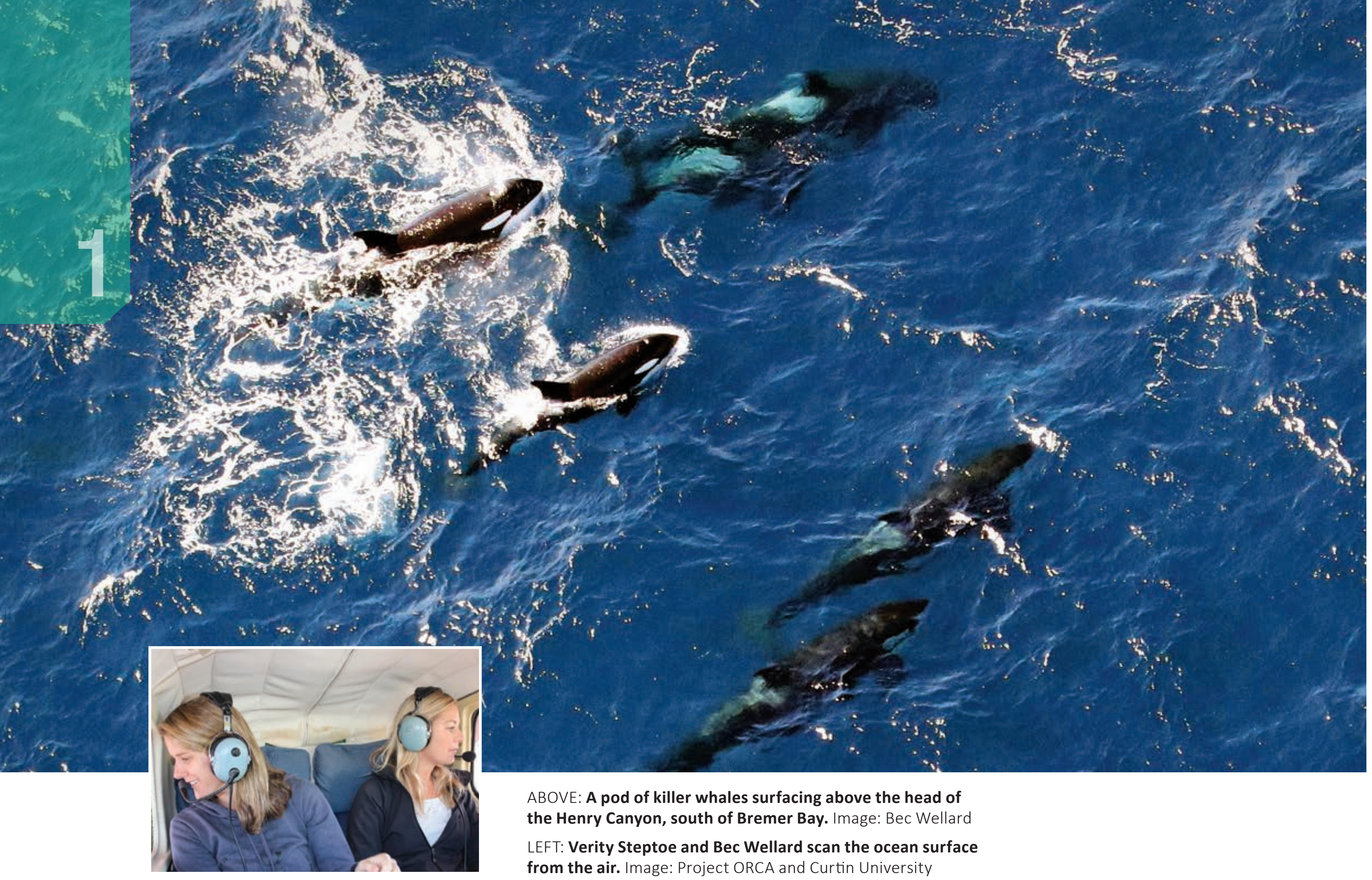
tim.langlois@uwa.edu.au

South-west Corner survey report

Harlequin Fish and Whiskery Shark. Image: The University of Western Australia

Deeper ledge habitat with bryozoans, hydroids and sponges. Image: The University of Western Australia

A Grey Nurse Shark at a depth of 141 m in the National Park Zone. Image: The University of Western Australia



ABOVE: **A pod of killer whales surfacing above the head of the Henry Canyon, south of Bremer Bay.** Image: Bec Wellard

LEFT: **Verity Steptoe and Bec Wellard scan the ocean surface from the air.** Image: Project ORCA and Curtin University

Watching whales, sharks and fishes at Bremer canyons

Some 55 km south-east of Bremer Bay off southern Western Australia, a group of canyons etched into the slope of the continental shelf plunge from depths of 200 m to more than 1000 m.

Long-finned Pilot Whales form groups of up to 60 individuals in the Bremer canyon region. Image: Curtin University

Above the canyons, marine life aggregates in high numbers, including whales, dolphins, and seabirds. The canyons are the site of the largest reported seasonal aggregation of Killer Whales in the Southern Hemisphere, with more than 100 identified individuals in the local population. This profusion of marine life is a mecca for ecotourism.

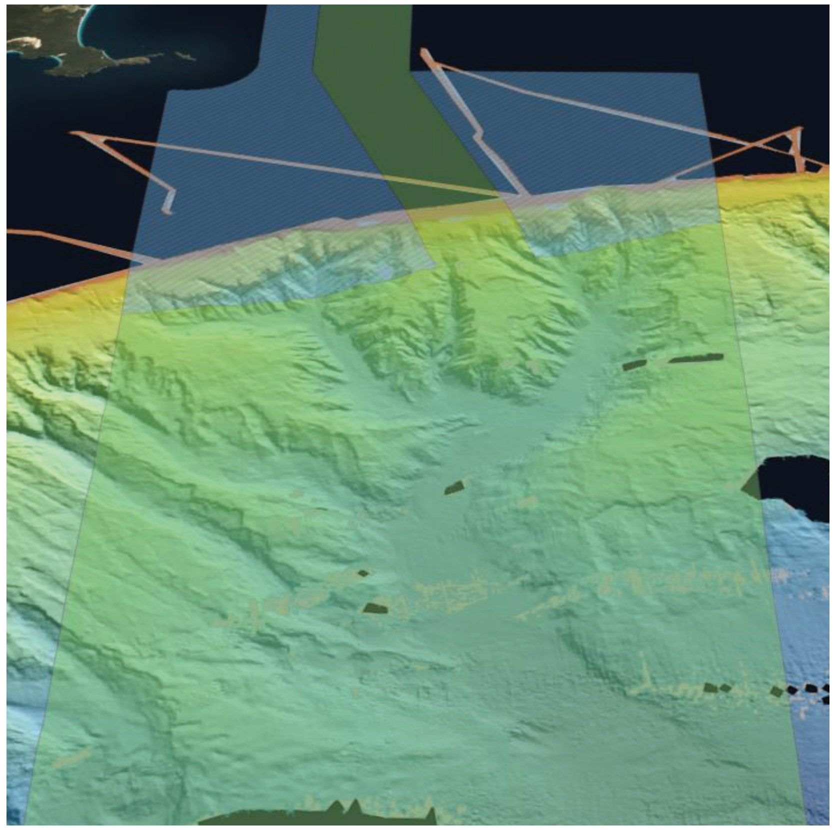
An inventory of this extraordinary biodiversity is needed to set a baseline for monitoring in the Bremer Marine Park, and guide the regulation of human activities in the park's multiple use zones. Associated challenges are to learn more about the movements, ecology and habitat of Killer Whales, and the drivers of the area's elevated productivity.

Survey and findings

A workshop in late 2016 gathered the perspectives of scientists, managers and stakeholders, identified existing knowledge and recommended research and management priorities. In February–April 2017, surveys led by The University of Western Australia gathered biological and oceanographic data.

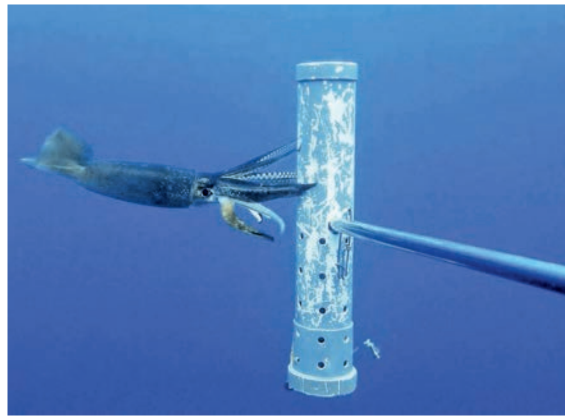
Aerial surveys were conducted along transects that crossed Bremer Marine Park and an adjacent area known to attract an abundance of large marine animals. A 10-day mid-water baited remote underwater video (mid-water stereo-BRUV) survey documented the diversity, abundance and biomass of pelagic sharks and fishes. During a six-week mission, an Integrated Marine Observing System (IMOS) autonomous underwater vehicle (Seaglider) dived hundreds of times to 1000 m depths, measuring temperature, salinity and biogeochemistry along repeat, sawtooth transects. Passive acoustic recordings and biopsies were also collected.

The aerial surveys identified four cetacean species: Killer Whales, Long-finned Pilot Whales, Sperm Whales, and the Bottlenose Dolphin. Sightings of False Killer Whales, as well as common, spinner and striped dolphins were made from vessels. The majority of species were observed as single animals or in pairs, although several larger groups of Pilot Whales, Killer Whales and Bottlenose Dolphins, 10 to 60 individuals strong, were also seen. Pilot Whales and Sperm Whales were widespread, with the latter recorded on most aerial transects. In contrast, Killer Whales were only



ABOVE: **Deep sea canyons south of Western Australia's Bremer Bay, including those in Bremer Marine Park, are a mecca for large marine life.** Image: Geoscience Australia

ABOVE RIGHT and RIGHT: **A Cock-eyed Squid (top) and an inquisitive Blue Shark investigate a mid-water stereo-BRUV.** Images: The University of Western Australia



detected close to, or westward of, the western park boundary. Preliminary analyses revealed no differences in the diversity or abundance of pelagic fish and shark species between sampling sites inside and outside the park.

The glider measurements confirmed that several different water masses interact in the region, and that the highest concentrations of chlorophyll occur at depth, though periodic mixing allows productivity to reach the surface layers. Minimal hydrocarbon traces were detected.

Outcomes and next steps

This Hub project provided the first regional picture of how large marine animals are distributed in and near Bremer Marine Park. It demonstrated the use of stereo-BRUV as a cost-effective, non-invasive monitoring approach and built on the results of a 2013 IMOS glider mission. Several previously undocumented Killer Whales were identified photographically, with images added to the Project ORCA catalogue.

The survey results support Australian Government decision-making to protect the environment and biodiversity and allow for sustainable use, and prioritise future research. They provide a critical baseline for understanding when and how cetaceans and other charismatic predators use Bremer Marine Park and nearby biologically important areas. Such knowledge is key to helping managers and policy-makers meet national legislative requirements regarding the adequate conservation of species listed under the *Environment Protection and Biodiversity Conservation Act 1999*. It also augments knowledge of the Albany canyon group and adjacent shelf break, which the *Marine bioregional plan for the South-west Marine Region* identifies as key ecological features. Repeat aerial and stereo-BRUV surveys at different times of the year will shed light on the variation in species occurrence and abundance across seasons and years.

FURTHER INFORMATION
jessica.meeuwig@uwa.edu.au
Bremer Canyon survey report

ABOVE: **Possible giant squid beaks sampled during the survey.** Image: The University of Western Australia and MIRG Australia

Bec Wellard of Curtin University prepares to deploy a towed acoustic logger. Image: Project ORCA and Curtin University

1 AUSTRALIAN MARINE PARKS

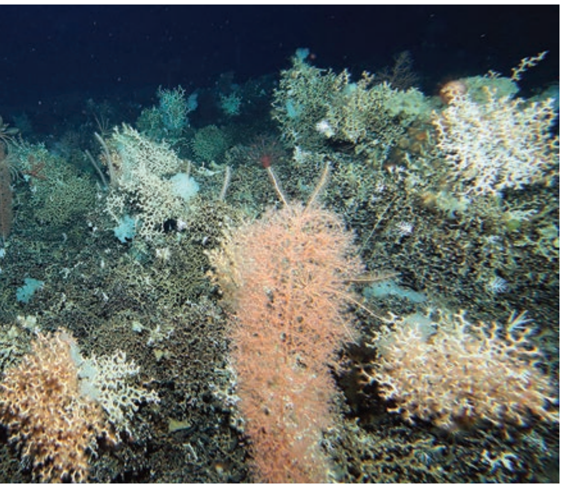
Identifying monitoring priorities

Parks Australia is developing approaches to better target the monitoring of Australian Marine Parks (AMPs) as part of an overarching management effectiveness system.

A major challenge in this process lies in developing a system for determining the optimal suite of data to collect across these vast and difficult to access environments. To ensure this system is effective, AMP managers need to know what lies beneath the sea surface, which features we value most and the benefits they provide, and where human activities pose the greatest risk to those values. A collaborative project between Parks Australia and the Marine Biodiversity Hub developed a pilot method for identifying monitoring priorities, using the South-east Marine Parks Network as a testing ground.

TOP: **Rariphotic shelf reef in Freycinet Marine Park.** Image: James Parkinson

BELOW: **Seamount reef in Huon Marine Park.** Image: CSIRO Marine National Facility



Developing the method

The project team began by developing a common terminology for all the things considered in AMP management. This includes natural values, social, cultural and economic benefits, pressures, management actions and 'drivers' (biophysical, social and economic). They engaged with specialists in marine protected area science and management, and drew on allied Hub research, to collate and synthesise existing knowledge of values and pressures.

Natural values mapping for the South-east Marine Parks Network defined the locations of more than 20 ecosystem types, and 11 key natural values across the network. The natural values were assessed for their vulnerability to individual activities and pressures. In general, natural values in deeper waters are less vulnerable, in terms of the number of potentially harmful activities and the magnitude of impact. The vulnerability assessment determined the combined impact of activities and pressures to identify which natural values (ecosystems) are most at risk. This analysis pinpointed important intersections between pressures and natural values. These are potential areas for management intervention, and as such they are also potential priorities for monitoring.

Final steps in the prioritisation process include checking which ecosystems are likely to be responsive to the management of pressures; whether values characteristic of the network have been adequately captured; whether sufficient information is available to form a monitoring baseline; and the feasibility of monitoring. Once the monitoring priorities are determined, monitoring questions articulate exactly what needs to be known about the values or pressures, in order to assess the achievement of conservation goals. These questions typically ask whether ecosystems or natural values are in the desired condition within a certain timeframe, following a management action.

Previous Hub research identified a set of generic indicators for different classes of natural values associated with AMP ecosystems. These indicators are the practical focus for monitoring. For example, data may be collected on the status of a particular invertebrate or fish species that might be expected to recover following the end of demersal trawling in the South-east Marine Parks Network. Similarly, generic indicators have been identified for key pressures affecting the conservation and protection of natural values. For example, sea surface temperature and ocean acidity are potential indicators of climate change.

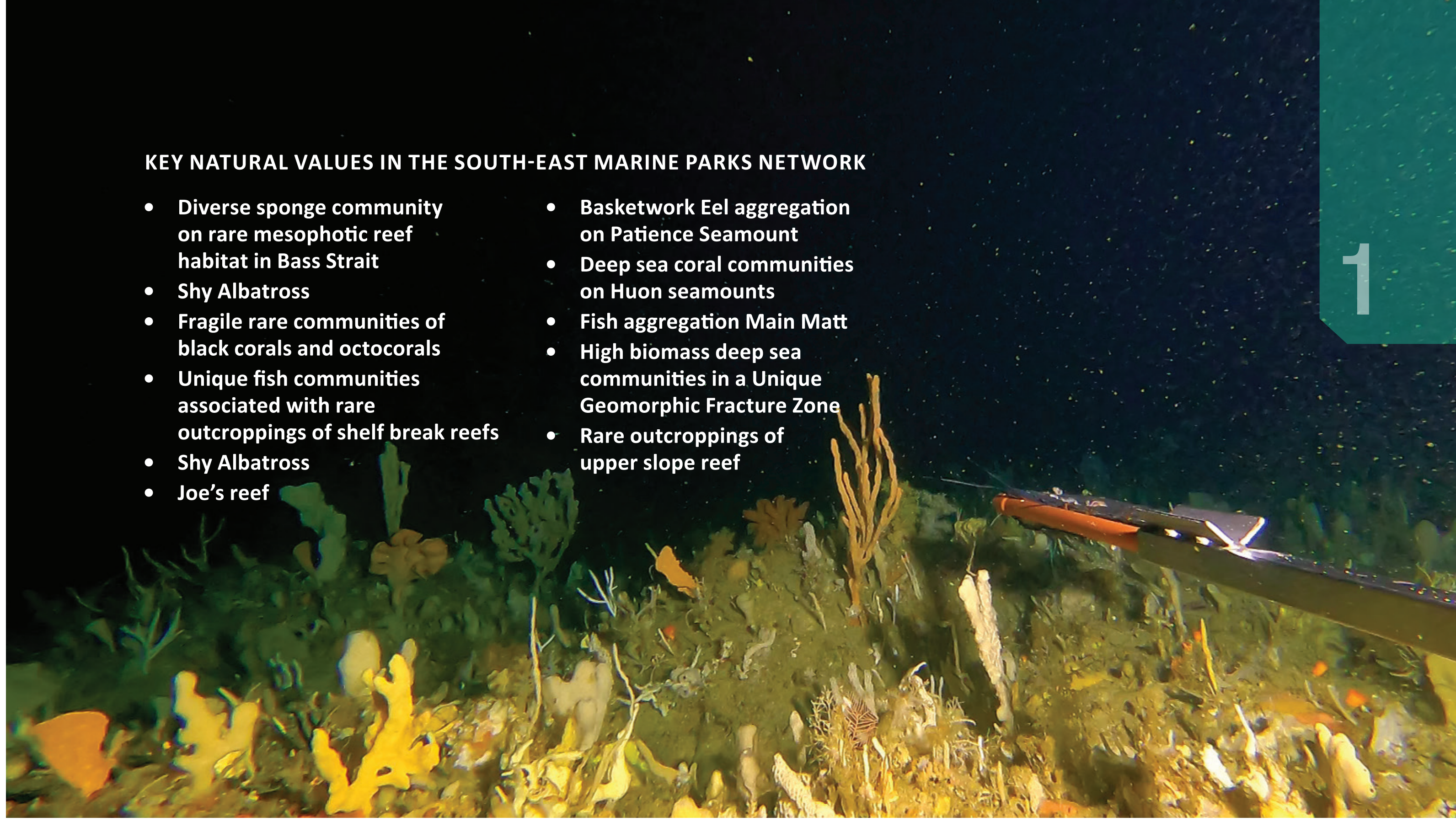
Outcomes and next steps

This project successfully developed a monitoring prioritisation approach for Parks Australia. As a direct result, the approach and associated products are being incorporated in science plans under development for each of the five AMP networks and the Coral Sea Marine Park. Elements of the approach will also contribute to a broader, parks-wide, management effectiveness system being developed by Parks Australia.

MORE INFORMATION

keith.hayes@csiro.au; piers.dunstan@csiro.au

Project report

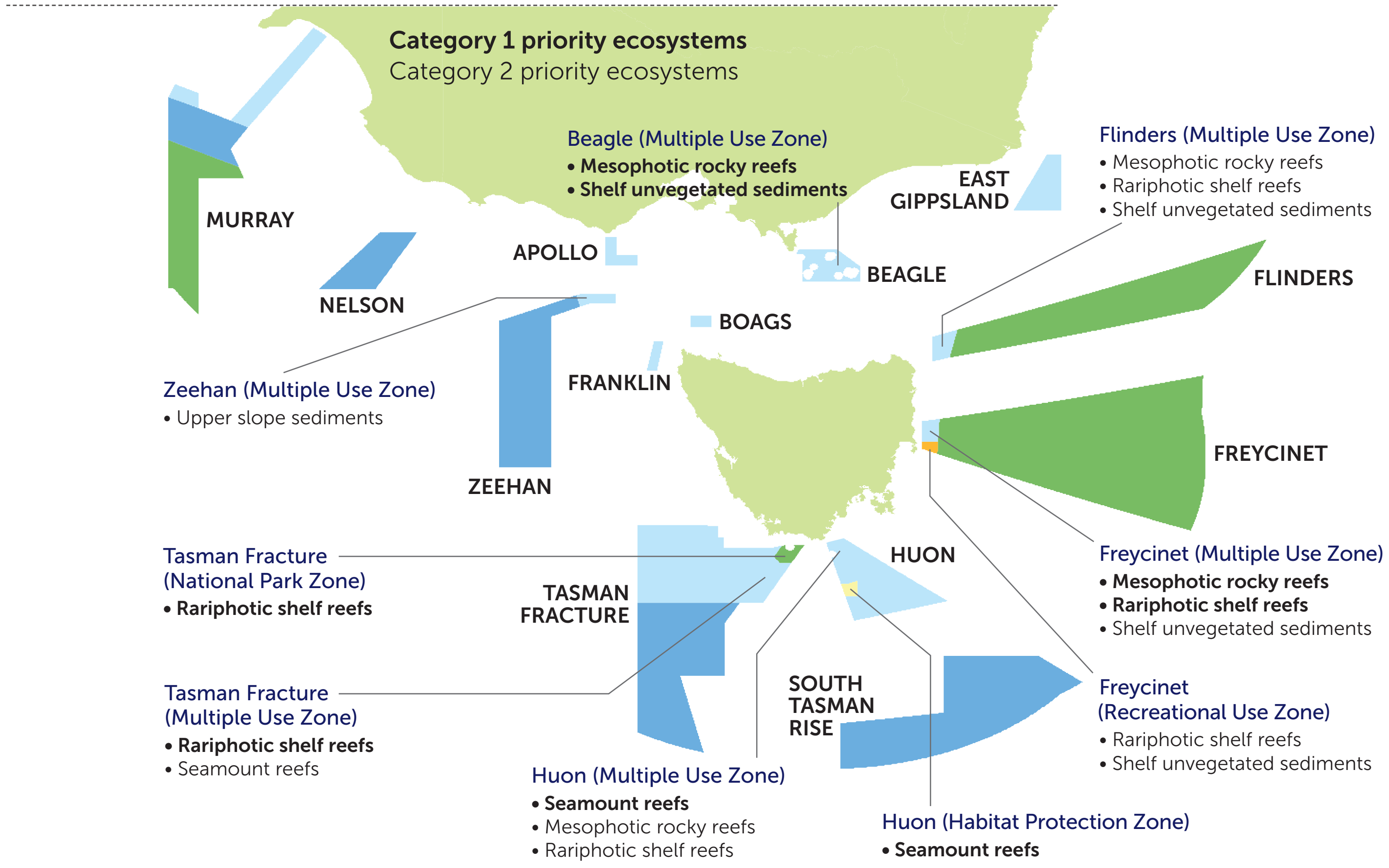


KEY NATURAL VALUES IN THE SOUTH-EAST MARINE PARKS NETWORK

- **Diverse sponge community on rare mesophotic reef habitat in Bass Strait**
- **Shy Albatross**
- **Fragile rare communities of black corals and octocorals**
- **Unique fish communities associated with rare outcroppings of shelf break reefs**
- **Shy Albatross**
- **Joe's reef**
- **Basketwork Eel aggregation on Patience Seamount**
- **Deep sea coral communities on Huon seamounts**
- **Fish aggregation Main Matt**
- **High biomass deep sea communities in a Unique Geomorphic Fracture Zone**
- **Rare outcroppings of upper slope reef**

Rariphotic shelf reef, Tasman Fracture Marine Park. Image: IMAS.

MONITORING PRIORITIES IN THE SOUTH-EAST MARINE PARKS NETWORK*



Zoning
- Marine National Park Zone (IUCN II)
- Habitat Protection Zone (IUCN IV)
- Recreational Use Zone (IUCN IV)
- Special Purpose Zone (IUCN VI)
- Multiple Use Zone (IUCN VI)

*This is a draft list of monitoring priorities pending approval of the *South-east Marine Parks Network Science Plan*

How do we value Australian Marine Parks?

Understanding the human dimensions of the Australian Marine Parks (AMPs), including awareness, use, perceptions, and economic value is critical to effective AMP management.

In this project, Hub researchers worked with Parks Australia and other marine park agencies around the country to identify and collect benchmark data on key social and economic measures. Four national surveys were conducted with a total of more than 4000 respondents. The surveys targeted a range of marine park users including recreational fishers, boaters and charter operators, as well as the general public.

Surveys and findings

The surveys revealed that most respondents supported no-take National Park Zones in AMPs. This included 80% of recreational fishers and 83% of non-extractive recreational boaters surveyed at boat ramps, and 75% of the general public surveyed online. These high levels of support were accompanied by views that no-take National Park Zones provided environmental benefits. In the general public survey 64% of respondents reported that AMPs did a good job in balancing conservation and sustainable use, while 28% thought they did not provide enough protection.

Relatively few marine users reported being negatively impacted by the zones in the AMPs. Ninety-seven percent of recreational fishers reported that their fishing experience either did not change, or benefitted from, the implementation of no-take National Park Zones.

While many people will never visit AMPs, the surveys reveal that Australians still value the protection of these areas. A choice experiment embedded in the general public survey showed that the average Australian was willing to pay $194 per year (for 10 years) for the present zoning arrangements in AMPs.

SUPPORT AND PERCEIVED CONSERVATION BENEFIT OF NO-TAKE ZONES IN STATE AND COMMONWEALTH MARINE PARKS

	State	Commonwealth	
	no-take	no-take	multiple use
general public		75%	65%
		80%	59%
recreational fishers	84%	80%	60%
	73%	72%	48%
charter operators	59%	57%	55%
	62%	62%	41%

support | perceived conservation benefit

Despite the largely positive views towards the AMPs, the surveys also reveal that there is work to be done in building awareness of AMPs. For example, just 22% of recreational fishers at boat ramps were aware of adjacent AMPs, compared with 90% awareness for adjacent state marine parks. To help build awareness, information about preferred contact methods was collected in the benchmark surveys.

To complement the surveys and develop a nuanced understanding of recreational use of the AMPs and the Australian coastline more generally, the research team also developed the first national model of recreational fishing effort. The model estimates numbers of line fishing trips around Australia and furthers our understanding of how Australia's oceans are used by recreational fishers, including the impact on their activities of AMPs.

Outcomes and next steps

This project established a robust approach to monitoring social and economic aspects of AMPs and collected benchmark social and economic data. The data are being used by Parks Australia to prioritise management actions and guide communication strategies. Follow-up surveys are planned to detect changes over time and evaluate progress towards objectives in Parks Australia's management effectiveness system.

FURTHER INFORMATION

matthew.navarro@uwa.edu.au

Social and economic monitoring final report

Jacquomo Monk.

Seeing beneath a sea of blue

Jacquomo Monk has spent the past six years developing monitoring approaches and biodiversity inventories for Australian Marine Parks (AMPs), from his desktop, and from the decks of assorted ships at sea.

Early in the NESP Hub, Dr Monk led a team that collated and synthesised public datasets describing reef habitats and communities on shelf areas of temperate AMPs. A workshop that articulated the immense value of integrating these data garnered broad support among research providers.

"It's interesting to reflect on the surprise impact of some of the work you do," he says. "Our 2017 synthesis document is reported to be frequently thumbed through by research users, primarily at Parks Australia. It identified the key assets, knowledge gaps and potential monitoring priorities for AMPs, and helped to catalyse national and international data repositories that now make this job so much easier. These include Seamap Australia, AusSeabed, GlobalArchive, and the Integrated Marine Observing System Understanding Marine Imagery (UMI) initiative."

GlobalArchive holds the details of thousands of baited remote underwater stereo video (stereo-BRUV) deployments collected in AMPs around Australia. It also records sampling off St Lucia in the Caribbean, where Dr Monk and local researchers applied the Hub's *Field Manuals for Marine Sampling to Monitor Australian Waters*. Dr Monk co-led three chapters of the manuals, bringing together world-class researchers to set standard practices for data collection.

"My experience of compiling national datasets has shown how difficult it is to extract a consistent story if the sampling design and techniques differ," he says. "We need to draw a line in the sand; from this point forward, let's all attempt to design our surveys and collect our data using the same standards. I think the full value of the manuals will become clear in next 10–20 years when we are trying to identify meaningful ecological trends for AMP managers."

Two papers co-authored by Dr Monk highlight the value already being drawn from large, nationally consistent datasets. The first found that no take reserves designed to optimise connectivity, size and depth range can be an effective conservation strategy for fished species. The second provided new insights into the impacts of human activity on larger fished species. "We found this pattern of human activity to be consistent from our most tropical northern reefs to our coolest kelp forests," he says. "Importantly, we also found that big fish can still be found within adequate no-take marine reserves on the doorstep of our largest cities."

Dr Monk says the process of developing and promoting the field manuals has also gained the participation of environmental consultancies involved with the oil and gas industry. He sees positive signs of increasing data transparency from this sector, which will be another key contribution to answering the big science questions.

Amid his syntheses and salty observations, Dr Monk has tracked seafloor life and invasive species inside and outside protected areas; summarised knowledge of specific AMPs; compared sampling platforms; and helped to develop monitoring indicators and a targeted monitoring program for the South-east Marine Parks Network.

He now co-leads the multi-year UMI initiative that is developing an open-source digital infrastructure to establish a national repository for annotations of marine imagery.

Dr Monk's cameras have shown him extraordinary environments in the depths of many AMPs: from Tasman Fracture and Lord Howe, to South-west Corner and the Coral Sea. "We have made incredible inroads into advancing a national monitoring system for AMPs", he says. "But each glimpse below the surface is a reminder of how little we really know about what lies beneath the sea of blue."

Jacquomo Monk trained researchers in the United Kingdom and the Caribbean to use stereo-BRUV based on the Hub's best practice procedures. He is pictured with the survey team at Soufrière, St Lucia. Image: Centre for Environment, Fisheries and Aquaculture Science

1 AUSTRALIAN MARINE PARKS

Meeting the needs of managers

Cath Samson.
Image: CSIRO Marine National Facility

The Marine Biodiversity Hub provided high-quality, relevant science to support management of Australian Marine Parks (AMPs).

From extensive data syntheses and challenging sea voyages, to one-on-one science interpretation, the Hub's contribution has been highly appreciated by the Parks Australia (PA) AMP management team.

Syntheses of existing data provided by the Hub are invaluable as a quick reference guide for marine park managers. They are used for familiarising new staff; environmental impact assessments; communication; identifying knowledge gaps and prioritising research. One of the most used reports in the Marine Parks Branch is: *Biological and habitat feature descriptions for the continental shelves of Australia's temperate-water marine parks – including collation of existing mapping in all AMPs*.

The identification and compilation of existing bathymetry data for AMPs was another key Hub project.

Cath Samson with Aero Leplastrier and Andrew Carroll of Geoscience Australia on the *Bluefin* during the Hub survey of Elizabeth and Middleton Reefs in Lord Howe Marine Park. Image: Geoscience Australia

Building on this great work, we now have a project with Geoscience Australia to include historical data in the AusSeabed portal. Hub 'econarratives' also provided useful knowledge summaries, for AMPs in the North, North-west South-west, Temperate east and South-east Marine Park Networks.

Another key component of the Hub's work was the AMP surveys. These have greatly increased our understanding of the types and distribution of natural values in several parks. Improved natural values information is critical for effective marine park management. You can't manage what you don't know is there! It supports environmental impact and risk assessments, and the PA Management Effectiveness system. The Hub is well placed to assemble the diverse science expertise required for these surveys and we would like to see voyages to AMPs continue under the new NESP program. We need to establish monitoring programs in many of the parks to support the AMP Management Effectiveness system, yet we still have large knowledge gaps.

The Hub's *Field manuals for marine sampling to monitor Australian waters* have enabled best practice, management-relevant research and national consistency in data collection and analysis. The Hub voyage approach and survey designs have informed many of our directly commissioned research projects, and our contract conditions typically require these best-practice approaches to be applied.

The Hub's social and economic baselines project made a major contribution to the PA management effectiveness system through identifying appropriate social, economic and awareness indicators and collecting social and economic baseline data for AMPs. The cost-benefit analysis provided by this project is helping PA to assess practical monitoring methodologies for future application.

Another key outcome of the Hub has been to build the science capacity of park managers. The knowledge scientists have generously and patiently shared has helped managers build their science understanding across a diversity of fields from ecology, common methods and new technologies, to socioeconomics. While we acknowledge many of us still have a long way to go, this increased literacy has been very valuable for engaging with scientists and colleagues on related work such as environmental accounting.

Next steps

The AMP management team looks forward to continuing collaborative work with the NESP Marine and Coastal Hub and through other projects and opportunities. Based on some of the learnings from the Hub, I see potential future opportunities in the areas of integrating Traditional knowledge with western science, and putting more focus on knowledge transfer from scientists to managers. This might include:

- developing manager relevant data summaries and visualisation products;
- streamlining the transfer of science information from scientists to managers using modern tools and technologies; and
- collaborating with the science community to build our data/information management needs into existing marine portals.

– Dr Cath Samson, Assistant Director – Science Planning and Operations, Parks Australia

2

Science for sustainable use

Tourism on the Great Barrier Reef.
Image: Shutterstock

Sunset over Oceanic Shoals Marine Park.
Image: Australian Institute of Marine Science

2

A toolkit for sustainable use, monitoring and management in northern waters

Australia's North and North-west marine regions are areas of high ecological diversity and expanding resource use.

Together the regions host 21 Australian Marine Parks (AMPs), 29 key ecological features (KEFs) and more than 250 marine and coastal species listed under the *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act 1999). They also support commercial and recreational fisheries, pearling and aquaculture, shipping, defence operations and oil and gas industries.

AMPs and EPBC-Act listed species are categorised as matters of national environmental significance (MNES). Under the EPBC Act 1999, any proposed activity likely to have a significant impact on a MNES may require referral to the Australian Government for assessment and approval. Ecological understanding of MNES is needed to identify proposed activities that require referral, and to support assessments, monitoring, and AMP and species management. This requires accessible baseline data and information on the distribution, abundance and diversity of habitats and species, and the factors that influence these patterns.

Hub researchers collated and synthesised extensive existing datasets and information, and collected new data, for the North and North-west marine regions. More than 100 curated datasets – including physical and biological surveys – were provided to the Australian Institute of Marine Science North West Atlas. A knowledge framework for the Oceanic Shoals AMP and the Ancient Coastline KEF was compiled to guide management and monitoring plans in these areas, and a preliminary qualitative model was developed for the Glomar Shoals KEF (see story on page 31).

Researchers used the expanded knowledge base to map seafloor habitat and biodiversity, and demonstrate methods for predicting distribution patterns across data poor areas. For example, coarse-scale seafloor hardness and sediment type was modelled and mapped across the regions. Other studies derived biodiversity and habitat associations for Oceanic Shoals Marine Park, mapped high-density areas for pelagic fish, and identified environmental predictors of Flatback Turtle behaviour.

Shoals, terraces and tidal fronts favoured by Flatback Turtles

Flatback Turtles are endemic to northern Australia. A better understanding of the turtles' foraging grounds, and the cues that direct them there from nesting sites, was needed to support the recovery of their populations. Turtles tracked by satellite transmitters migrated from the Lacepede Islands to foraging grounds on the mid-Sahul Shelf, allowing researchers to link variables such as geomorphology and sediment type with migration, and tidal fronts and turbidity with foraging sites. Foraging, nesting and transiting behaviours were also revealed.

The turtles favoured clear waters of 60–90 m depths, and banks, shoals, terraces, deep holes and valleys thought to support plentiful attached invertebrates. Distance to the tidal front was also a strong predictor of turtle migratory behaviour, with the turtles apparently following tidal fronts along the Kimberley coast. While the nesting grounds and transitory pathways to the nesting grounds were well encompassed by AMPs, only about half of the core foraging area was encompassed, although 70% of their time was spent there.

LEFT: A Flatback Turtle at West Lacepede Island. While Flatback Turtle nesting grounds and transit routes are well encompassed in AMPs, core foraging grounds are comparatively under-represented.
Image: David Waayers, Imbricata Environmental

FURTHER INFORMATION

k.miller@aims.gov.au

Ecosystem understanding in the North and North-West regions

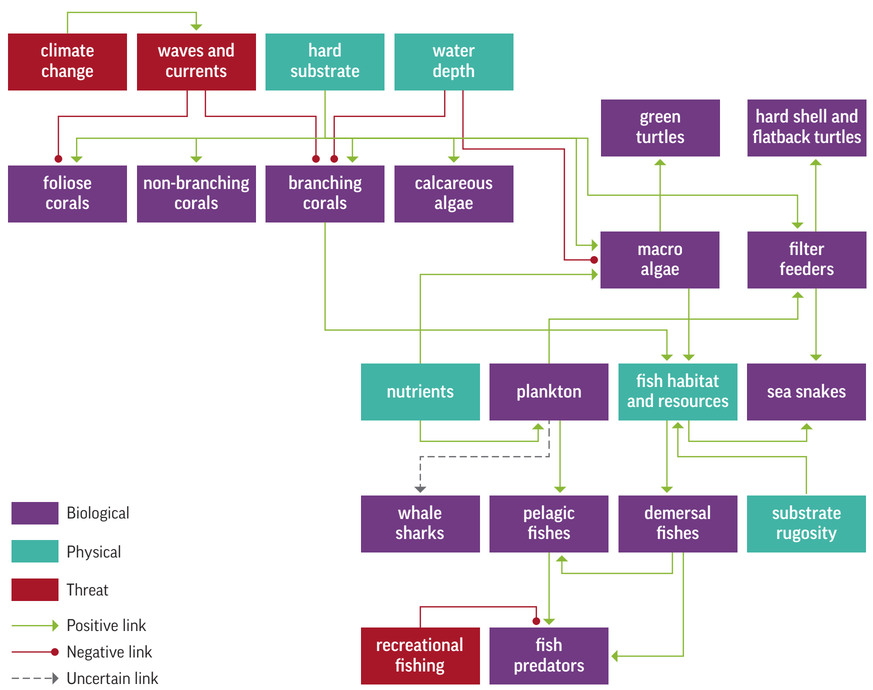
A toolbox of predictive models for the North and North-west regions

Fisheries data connect submarine canyons and large predators

Understanding the broad-scale movements of pelagic predators is important to planning and management of marine protected areas. A Hub study used commercial fishing records from the Sea Around Us project to model the distribution of large predators such as tunas, marlins, mackerels, and identify any relationships with prominent seafloor features. The occurrence and density of submarine canyons was the best predictor of regional fish abundance in the north, highlighting the potential relevance of topography to zoning and spatial management.

Image: Jessica Meeuwig, UWA.

GLOMAR SHOALS KEY ECOLOGICAL FEATURE QUALITATIVE MODEL



The Glomar Shoals model identifies ecological interactions and potential threats. Based on this simple structure, two key threats appear plausible within a 50-year time frame. The first is increased storm intensity due to climate change, which most strongly affects foliose and branching hard corals. The second is increased pressure from recreational fishing, which targets the fish predator group in the model.

Glomar Shoals model shows ecological links, potential indicators and threats

Key ecological features (KEF) are elements of the Commonwealth marine area that are considered important to regional biodiversity or ecosystem function and integrity. Nationally, 56 KEFs are identified in marine bioregional plans.

Glomar Shoal KEF in the North-west Marine Region covers 770 km² and rises from a depth of 75 m to 30 m. This typical outer shelf terrace habitat attracts aggregations of marine life. A preliminary qualitative model was developed based on new knowledge of the area's seafloor and pelagic environments to help identify threats and potential ecological indicators for monitoring and management.

The mixed substrate of carbonate hardground and sediments at Glomar Shoals provides habitat for corals, octocorals, sponges, coralline algae and macroalgae. Branching corals, macroalgae and filter feeders support fishes and sea snakes, and the diversity of fish habitat is enhanced by the uneven topography.

Demersal fishes are preyed upon by an array of pelagic and demersal fish predators, the latter of which are caught by recreational fishers. Glomar Shoal is an important feeding area for Green Turtles, which consume macroalgae, and Flatback Turtles, which consume seafloor filter feeders.

Surface waters of the North West Shelf are generally low in nutrients, but tidal fronts and internal waves may drive plankton production with pulses of nutrients. This productivity is important to filter feeders, pelagic fishes, and possibly whale sharks. High cyclone activity can lead to strong wave and current energy that is especially destructive to corals in waters shallower than 30 m.

Predicting habitat across Oceanic Shoals Marine Park

Oceanic Shoals Marine Park is one of the largest and better studied Australian Marine Parks (AMP) in the north-west, but even here, high resolution data exist for only a small fraction of its expanse.

A Hub project combined biodiversity data from previous Hub surveys with physical data such as bathymetry to develop predictive models for the park. The models mapped a coarse patchwork of seafloor habitats, pelagic species, sponge diversity, and sediment type and hardness, providing a basis for targeting future surveys, and ultimately the development of finer scale habitat models. Such models can help researchers and managers investigate biodiversity patterns and associated physical and biological influences, relationships between species and habitats, and habitat disturbance.

Mapping seabed craters and critters

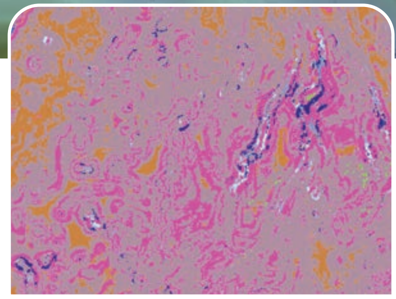
Pockmarks are seabed craters where fluids (gas and liquids) push up through fine-grain sediments, often around carbonate banks and ancient, buried river systems. Understanding pockmarks can help scientists predict seafloor habitats and associated marine life. A Hub study used survey data to characterise the geochemical, sedimentological and biological properties of the world's highest density known pockmark fields. The new insights for Oceanic Shoals MP support the modelling of seafloor biodiversity patterns and current and tidal flows.

Modelling biological connectivity

Connectivity modelling (based on brittle stars) developed in earlier Hub research was applied to examine biological links between Oceanic Shoals MP and other parks in the North and North-west marine regions. The results indicated that nearly 80% of larvae were likely to remain in the Oceanic Shoals MP, and that the park contributed larvae to and received larvae from several other AMPs. Applying the model to actual biological collections could identify potential sinks and sources relevant to marine zoning and management.

Polychaetes diverse and uniquely placed

Polychaetes (marine worms) collected in previous Hub surveys at Oceanic Shoals indicate the region may be a hotspot for polychaete biodiversity. A total of 368 species and 43 families of polychaetes were counted from 266 samples, with new species, genera, and family records. Plains and banks supported distinct polychaete assemblages, and the environmental relationships differed from those of sponges surveyed. This new understanding for the northern Australian shelf provides a baseline for monitoring programs.



TOP: **Pockmarks appear as tiny pin-pricks on a bathymetry map of Oceanic Shoals Marine Park.** Image: Geoscience Australia

ABOVE: **Predicted patterns of sponge species richness trace the contours of the park's banks, terraces, valleys and plains.** Image: Geoscience Australia

BELOW FROM LEFT: **A new polychaete species from the *Polyodontes* genus.** Image: Chris Glasby.

A diversity of sponges: Oceanapia, cup sponge, barrel sponge. Images: Belinda Alvarez, Geoscience Australia.

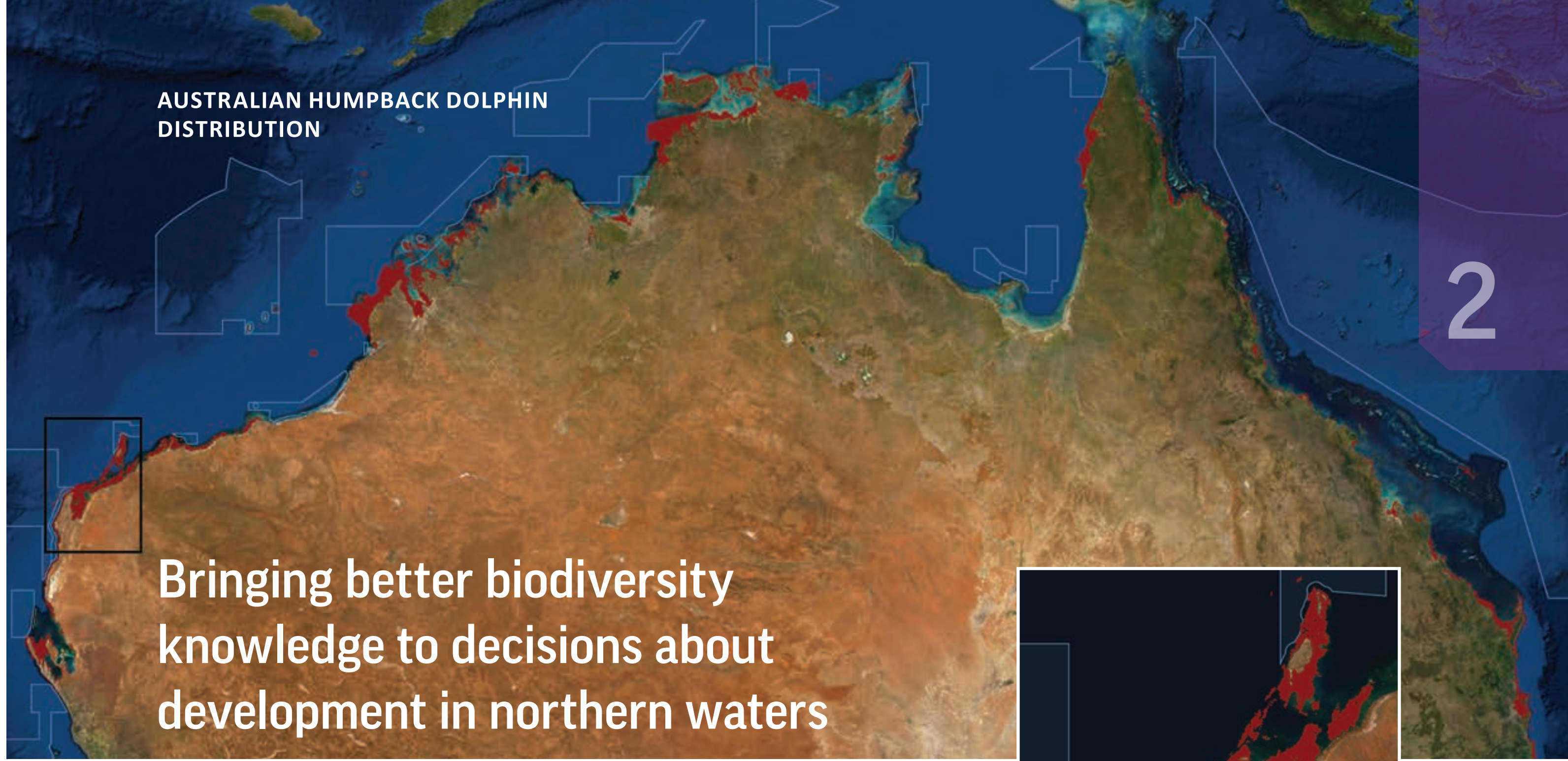
Predicting sponge species richness

Understanding the distribution of sponge species richness and its relationship with the environment is important for prioritising management and conservation of sponges, and designing monitoring programs. Several modelling approaches were combined to develop a flexible approach for Oceanic Shoals MP. Species richness was predicted to be high on banks and terraces and low on plains and valleys.

FURTHER INFORMATION

rachel.przeslawski@dpi.nsw.gov.au
Polychaetes of the Oceanic Shoals region
Developing a toolbox of predictive models

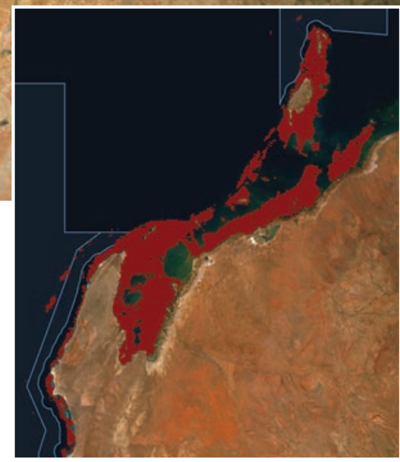
kim.picard@ga.gov.au
Origin of high-density pockmark fields



Bringing better biodiversity knowledge to decisions about development in northern waters

Northern Australia harbours critical nesting and breeding sites, foraging grounds and migration routes for threatened and migratory marine species including sharks and rays, Dugong, whales, dolphins, turtles, sea snakes and birds.

Information on species' distributions, habitat and population connectivity are needed to support biodiversity conservation in the context of the area's economic development. For many species, however, data were limited and disjointed. Hub studies updated the knowledge base by aggregating datasets and generating distribution models for priority species, identifying Green Sawfish nurseries, and examining the genetic structure of shark and sawfish populations.



Distribution maps for the Australian Humpback Dolphin and Largetooth Sawfish, across Australia and for selected areas of interest (Exmouth-Ningaloo and Fitzroy River). Areas of modelled habitat suitability are dark red. Australian Marine Park boundaries are light blue. Images: Australian Institute of Marine Science

Approach and findings

Hub researchers collaborated with data custodians around Australia to collate more than 120 datasets covering species occurrence and habitat suitability for 16 priority threatened and migratory marine turtles, Dugong, shorebirds, whales, dolphins, sharks, sea snakes and sawfishes. Several key determinants of suitable habitat, such as bathymetry, and occurrence data for river shark and sawfish species, were drawn from other Hub studies. Habitat suitability modelling based on the combined datasets predicted species distribution across the North and North-West Marine Regions. The newly acquired and aggregated data and prediction of habitat suitability into data poor areas resulted in more extensive and detailed maps than previously were available at this scale.

Outcomes and next steps

Decision-makers now have an improved evidence base to support the assessment of development proposals under the *Environment Protection and Biodiversity Conservation Act 1999*. The maps can be viewed on the Australian Ocean Data Network and datasets were provided to the Department of Water and the Environment (DAWE) Species Profile and Threats database. The datasets and established modelling procedure can be used to update species distribution maps once more data become available.

The modelling identified priority locations for future surveys, with the most notable data gaps being for river sharks, sawfishes and Hawksbill Turtles. It could also be used to assess overlaps between habitats and pressures, which have been mapped in allied Hub research. This may identify key pathways for the management and recovery of threatened marine species. For many of these species there is a need to identify habitat suitability at finer scales.

FURTHER INFORMATION

mthums@aims.gov.au
Distribution and habitat suitability of threatened and migratory marine species

Rating the habitat in Australia's 753 submarine canyons

Submarine canyons are steep-sided valleys cut into the sea floor that trap nutrients and attract a diversity of marine life. They funnel nutrient rich waters up onto the continental slope and shelf, fuelling feeding grounds for fishes, whales and other cetaceans. Communities of sponges and corals grasp their hard walls, and the tiniest of creatures collect in their sediments.

Australia has more than 750 submarine canyons. Most of these are in the south, and many are in Australian Marine Parks, or form key ecological features (areas of exceptional ecological value). All these canyons have now been rated for their habitat potential, in a Hub study led by Geoscience Australia. This is the first time that the physical variability of Australian submarine canyons has been related to likely habitats and marine communities.

Approach and findings

To visit all the canyons would have taken forever, so rather than going to sea, the research team scoured previous studies for links between canyon features and marine life. Using this knowledge they developed and applied an analytical framework for estimating the potential of individual canyons to support pelagic (open ocean) and benthic (seafloor) species, including bottom-dwelling fishes.

Four aspects of canyon habitats – shape, size, topography and substrate type – were of particular interest and could be gleaned from seabed mapping. Assessments of organic matter, inorganic nutrients, oxygen and chlorophyll-a (a sign of phytoplankton), and oceanographic factors such as currents, were used to rate levels of productivity. Based on the available information, 22 environmental features were analysed as signs of habitat potential.

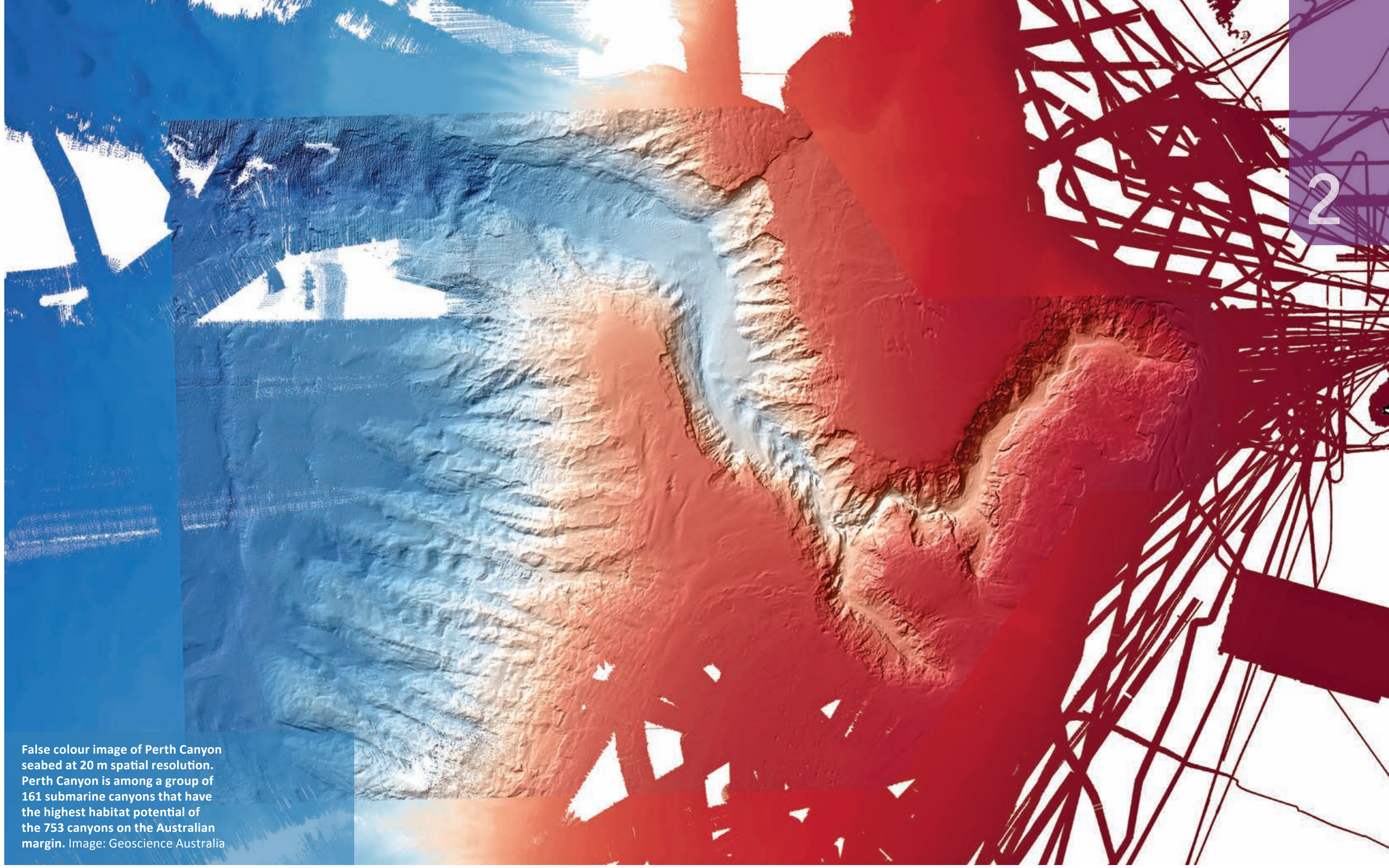
Of the 753 Australian submarine canyons, 135 offer good habitat potential for at least one of the three marine species categories: 13 are good for pelagic species, 36 are good for epibenthic species, and 124 are good for infauna species. Most of these good potential canyons are located off the east coast, and some are in the south, including the Albany canyons off Western Australia.

Five 'super canyons' were identified that have good habitat potential for all three communities. These were located off the Great Barrier Reef and New South Wales, and had particularly high habitat potential for both pelagic (open ocean) and seabed animals. Next in the ranking were canyons east of Tasmania, in the Murray group off South Australia and the Albany group off southern coast of Western Australia.

Most of the super canyons have complex bottom topography, and are situated in narrow parts of the continental margin nearer to terrestrial nutrient sources and with bottom currents that deliver food particles and generate intermediate 'disturbance'. They also are brushed by the East Australian Current which, aided by frequent, wind-driven upwelling events, lifts nutrients from deeper waters towards the surface.

The results showed that in general, canyons that extend onto the continental shelf tended to score higher in habitat potential than those confined to the slope. And overall, canyons provide a better neighbourhood for animals that live in the seafloor sediments than for those that live above them. Canyons with good habitat potential that also intersect an Australian Marine Park are found mostly in the east. In the south-east and temperate east regions, 29 canyons lie partly within nine Australian Marine Parks, including Tasman Fracture, Freycinet, Flinders, Murray, Jervis, Hunter, East Gippsland, Lord Howe and Central Eastern Marine Parks.

The Great Barrier Reef marine park also offers protection to a high proportion of canyons with good habitat potential, with 30 canyons intersecting the park. In contrast, only two canyons from the south-west region and one from the north-west were classed as having good habitat potential.



False colour image of Perth Canyon seabed at 20 m spatial resolution. Perth Canyon is among a group of 161 submarine canyons that have the highest habitat potential of the 753 canyons on the Australian margin. Image: Geoscience Australia

Outcomes and next steps

The framework for assessing canyon habitat – once refined and validated with ecological data – can support conservation and management decisions, especially for high value canyons, such as the prioritisation of monitoring, which might focus in the east, and to a lesser degree the south.

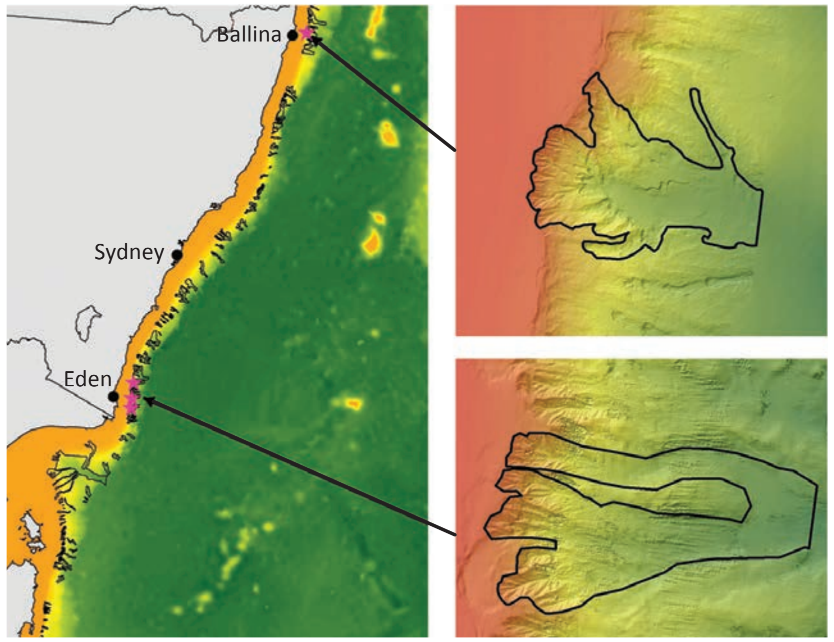
Apart from the habitat potential of these canyons, however, little is known about them. Multi-disciplinary surveys and studies are needed to collect baseline environmental and biological information in these important ecosystems.

FURTHER INFORMATION

zhi.huang@ga.gov.au

A framework to evaluate submarine canyons

Perth canyon eco-narrative



Two examples of 'super canyons' located off the New South Wales coast. They have particularly high habitat potential for both pelagic (open ocean) and seabed biota. Image: Geoscience Australia

Pockets of Narrow Sawfish drawn for fisheries management

Threatened sawfish species are prone to incidental capture by commercial fisheries because their distribution overlaps with target species and their rostral teeth are easily snagged in nets.

Australia is the last global stronghold of the Narrow Sawfish, which is the most common of four sawfish species caught as bycatch across northern Australia. While trawl nets are fitted with bycatch reduction devices, interactions still occur, and post-release survival rates for Narrow Sawfish are unknown.

Approach and findings

A Hub study analysed the DNA of Narrow Sawfish tissue samples to see how populations are divided across northern Australia. A key question was whether Narrow Sawfish move and breed across major fishing regions, or breed in the region where they were born.

More than 350 samples were accessed through a collaboration with fisheries and fishery agencies including the Northern Prawn Fishery (NPF) and the Northern Territory Offshore Net and Line Fishery. The collection of sawfish tissue samples for analysis of population abundances and connectivity is an action identified in the *NPF Bycatch Strategy 2020–2024*.

The DNA analysis indicated that while female Narrow Sawfish breed in the region where they were born, the males roam between regions. Based on this limited female dispersal – known as philopatry – five distinct populations were identified in regional fishery areas (but philopatry potentially occurs at a finer scale). The distinct regional populations have implications for Narrow Sawfish conservation. If bycatch mortality rates were to exceed biological productivity in any region, populations would become depleted because females would not replenish from elsewhere. Furthermore, regional pressures will differ. Regional-scale monitoring and management may therefore be necessary to maintain populations.

Outcomes and next steps

This study provided critical Narrow Sawfish population information to fishery managers, threatened species managers, and the fishing industry. It mapped populations in relation to the regional footprints of commercial fishing. This is critical to understanding the risk of fishing to Narrow Sawfish and the potential for spatial management to mitigate that risk. The study also showed that collaboration with the fishing industry is an efficient means of obtaining extensive samples of Narrow Sawfish from a broad region. Future priorities are to study post-release survivorship of bycatch sawfish and female philopatry at the estuary scale.

TOP LEFT: **A trawler in the Northern Prawn fishery.** Image: NPF Industry

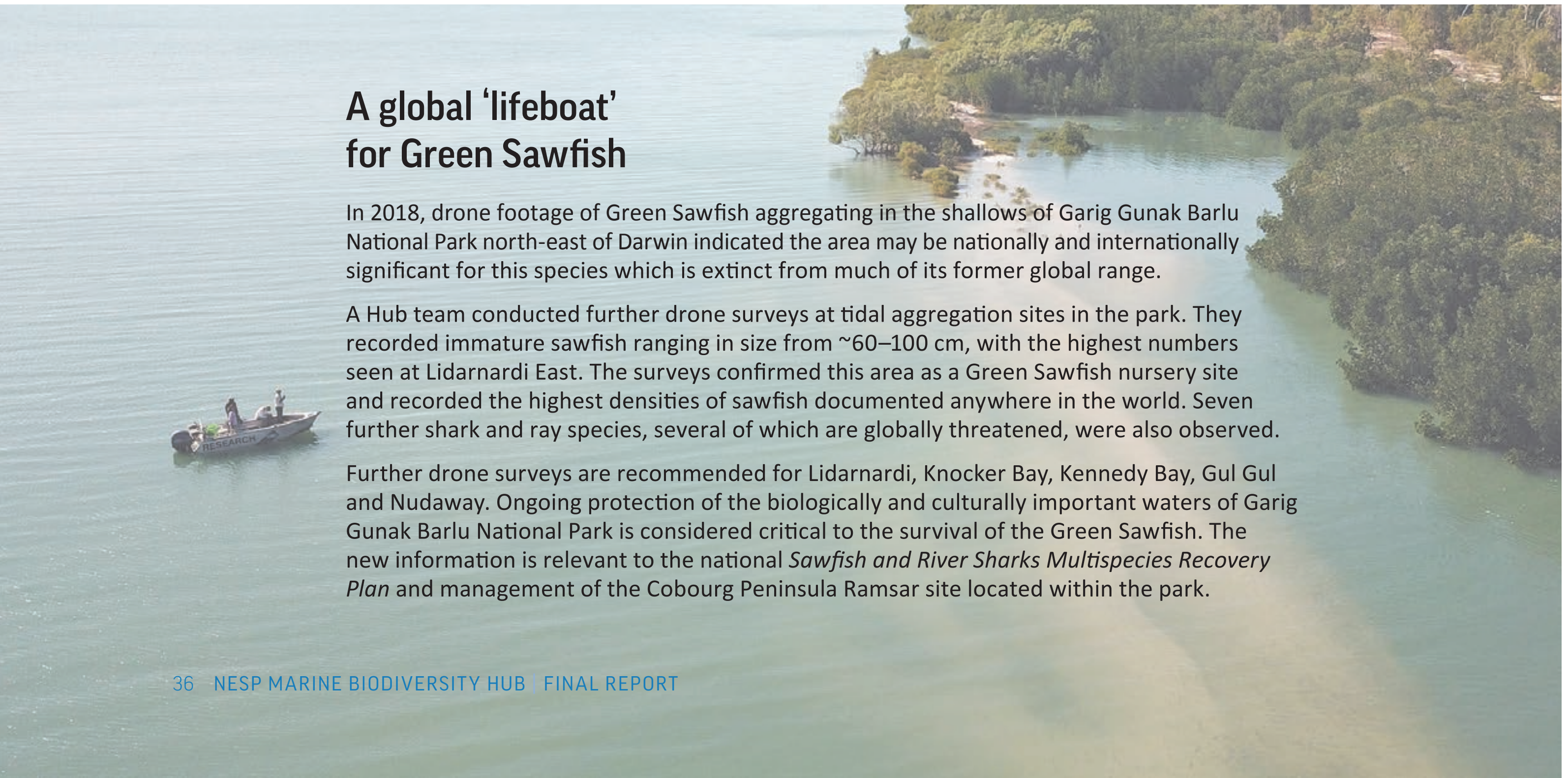
BELOW: **Surveying Green Sawfish habitat, Knocker Bay Garig Gunak Barlu National Park**. Image: Thomas Tothill

FURTHER INFORMATION

peter.kyne@cdu.edu.au

Population structure of Narrow Sawfish

Green Sawfish aggregation surveys

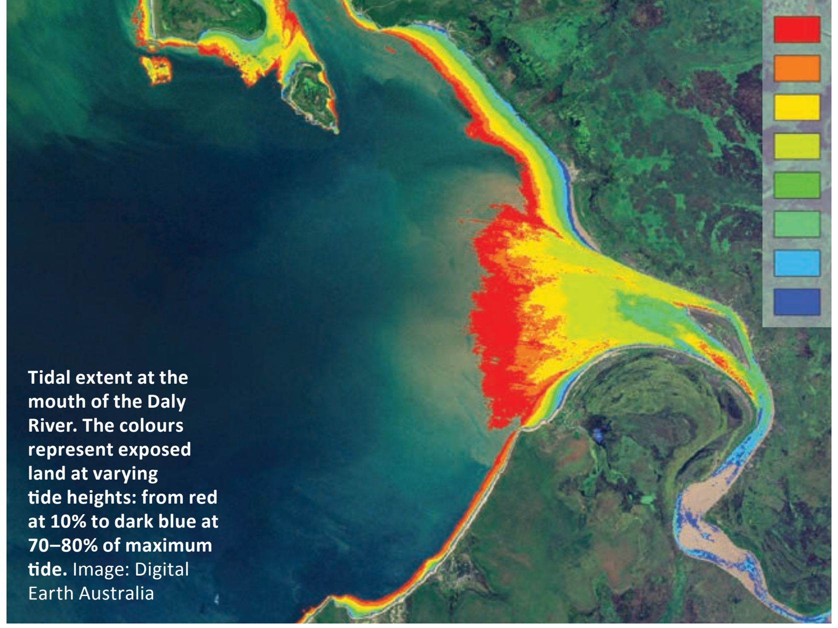


A global 'lifeboat' for Green Sawfish

In 2018, drone footage of Green Sawfish aggregating in the shallows of Garig Gunak Barlu National Park north-east of Darwin indicated the area may be nationally and internationally significant for this species which is extinct from much of its former global range.

A Hub team conducted further drone surveys at tidal aggregation sites in the park. They recorded immature sawfish ranging in size from ~60–100 cm, with the highest numbers seen at Lidarnardi East. The surveys confirmed this area as a Green Sawfish nursery site and recorded the highest densities of sawfish documented anywhere in the world. Seven further shark and ray species, several of which are globally threatened, were also observed.

Further drone surveys are recommended for Lidarnardi, Knocker Bay, Kennedy Bay, Gul Gul and Nudaway. Ongoing protection of the biologically and culturally important waters of Garig Gunak Barlu National Park is considered critical to the survival of the Green Sawfish. The new information is relevant to the national *Sawfish and River Sharks Multispecies Recovery Plan* and management of the Cobourg Peninsula Ramsar site located within the park.



Tidal extent at the mouth of the Daly River. The colours represent exposed land at varying tide heights: from red at 10% to dark blue at 70–80% of maximum tide. Image: Digital Earth Australia

Harnessing satellite imagery to detect and monitor change in coastal habitat

Australia's river estuaries and coastal wetlands provide vital habitat for threatened and migratory species.

Monitoring change across these vast and dynamic areas is challenging using traditional surveying techniques. Two Hub studies explored earth observation (satellite imagery) as a potential solution.

Approach and findings

The first study used calibrated earth observation data and analytical capabilities provided by the Australian Geoscience DataCube (AGDC) to explore coastal change in Moreton Bay, Queensland, and the Murray River Mouth, South Australia, dating back almost 30 years. It determined the distribution and timing of coastal change in highly dynamic coastal environments, and showcased shape-shifting coastal features such as the Murray Mouth for research users.

AGDC subsequently matured into Digital Earth Australia (DEA). The second Hub study mapped coastal habitats using 30-years of Landsat imagery archived on DEA for the Keep, Daly, Roper, Macarthur, Flinders and Gilbert River estuaries and Darwin Harbour. The Geoscience Australia Intertidal Extents Model (ITEM v2.0) was teamed with a tidal tagging and modelling process to depict highest and lowest tides and discern between tidal-induced and long-term change. The resulting images show coastal features visible above the water line at each tidal extreme, providing a baseline understanding of the extent and dynamics of critical habitats. Low tide images revealed intertidal substrate types, and persistent islands and sandbars in channels and offshore. High tide images showed the typical extent of the high tide water mark and interacting habitats.

Analysing the long and detailed archive of Landsat imagery provided unique insights into the form, timing and rate of change in estuarine landforms and habitats. While some changes were gradual, others traced specific events. There was large-scale rapid island growth and mangrove expansion in the Keep River and Gilbert River estuaries; gradual long-term mangrove expansion in the Flinders River and McArthur River estuaries; and rapid mangrove dieback in the Roper River and Flinders estuaries.

Outcomes and next steps

This cost effective approach could be applied to monitoring vast remote areas, and prioritising intensive studies, to support the management of key species, and decision-making related to coastal development. The next step is to validate and classify the Landsat archive using on-ground data. This would provide baseline information for monitoring key threatened and migratory species populations and habitat, investigating changes in habitat and species distribution, and predicting undocumented areas of critical habitat.

Isolated Speartooth Shark populations require river-scale management

Speartooth Sharks inhabit rivers and estuaries of northern Australia and southern Papua New Guinea (PNG). Genetically distinct populations were known to exist in Australia's Wenlock River, Alligator Rivers and Adelaide River.

A Hub study added to this knowledge, with genetic analysis of newly-identified populations in the Ord and Daly rivers of northern Australia and the Kikori river of PNG showing that these populations are also distinct.

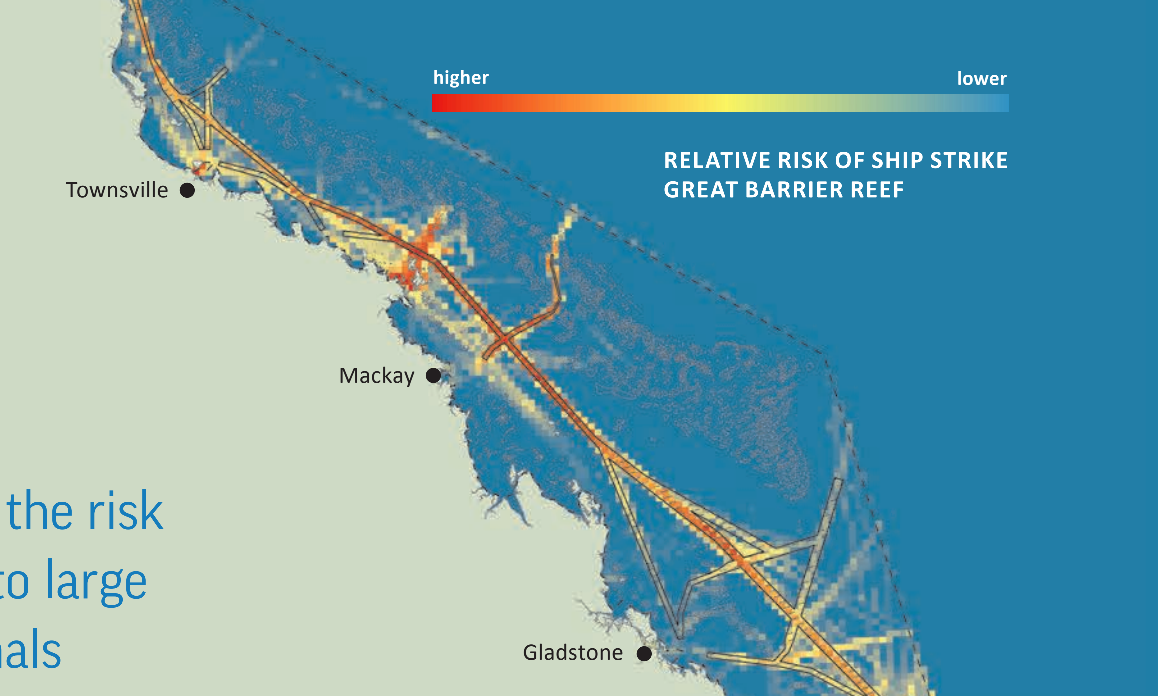
The identification of isolated populations highlights the need for Speartooth Shark management to apply at the individual-river scale, because isolated populations, if depleted, cannot be replenished from elsewhere.

BELOW: **Peter Kyne of Charles Darwin University with a Speartooth Shark pup.** Image: Charles Darwin University

FURTHER INFORMATION

peter.kyne@cdu.edu.au

Complete mitochondrial genome of the Speartooth Shark



Quantifying the risk of shipping to large marine animals

Sea transport is vital to the Australian economy. We rely on sea transport for 99% of our exports, and much of our domestic freight depends on coastal shipping.

Vessel activity at Australian ports is rising steadily. Larger vessels are venturing farther offshore and recreational boating is expanding in most regions, raising the potential for adverse interactions. Two major risks are collisions with marine life and chronic anthropogenic ship noise.

In this Hub project, researchers worked collaboratively to identify and address specific needs of research users including the Australian Maritime Safety Authority, Defence Science and Technology Group, Department of the Environment, Parks Australia and the Great Barrier Reef Marine Park Authority.

Collisions between vessels and large marine animals are of increasing concern, particularly where high volumes of vessel traffic overlap critical resting, breeding and feeding areas. The Commonwealth *National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna* identified the need for data acquisition and analysis to determine the risk of vessel strike. Hub research identified areas of higher relative risk, based on new mapping of Australian vessel traffic and the density of priority species. A comprehensive review of historical reports yielded new insights into the rates and severity of reported vessel collisions with whales.

Underwater radiated noise from shipping can also have adverse impacts on marine mammals. In 2014 the International Maritime Organisation adopted guidelines to reduce this noise, in recognition of its effects on the life cycles and behaviour of marine animals. The Hub's ocean noise research demonstrated techniques for fine-scale national ocean noise mapping and produced the first national map of cumulative noise from large commercial vessels.

Approach and findings

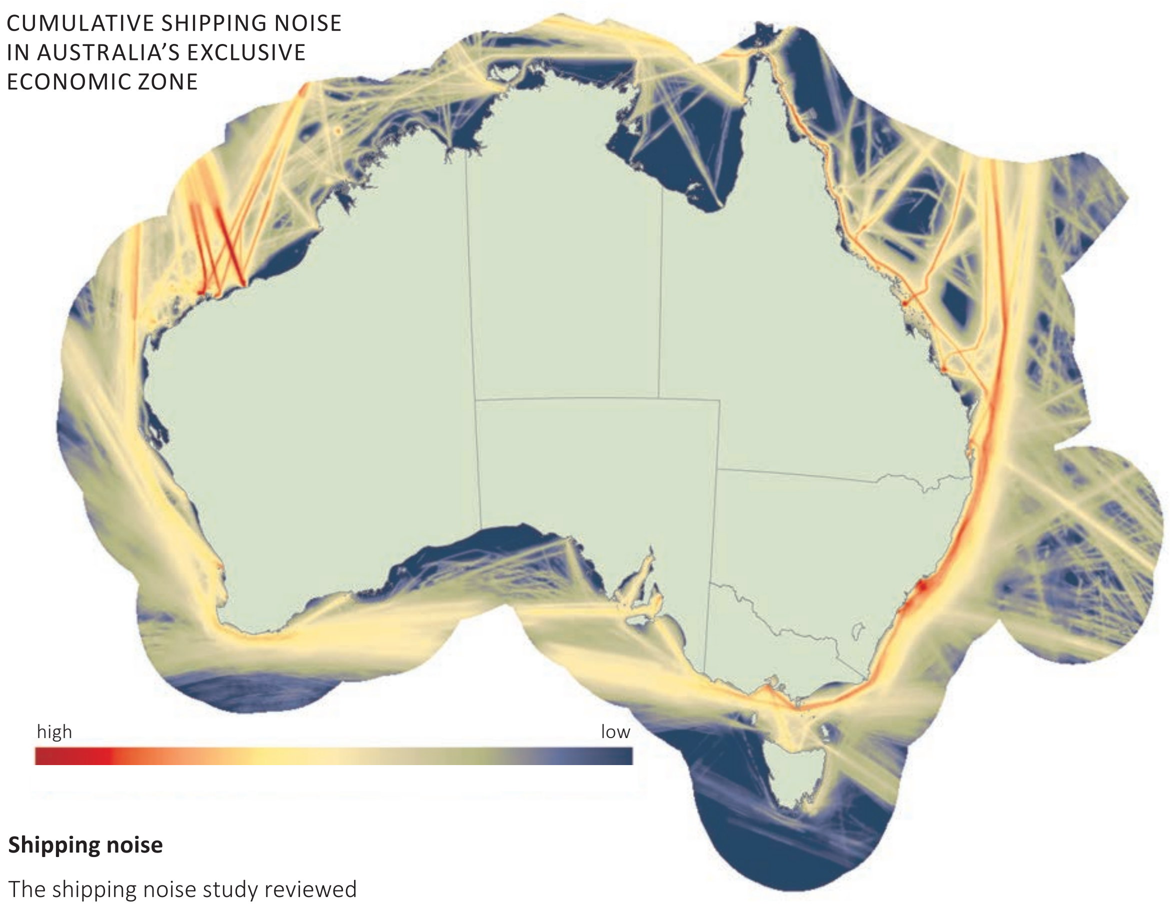
Ship strike risk

Quantifying vessel collisions with whales is an enormous challenge. Nations contribute voluntarily to a global database maintained by the International Whaling Commission (IWC), but historically reporting is inconsistent and the Southern Hemisphere poorly represented. A global search of media archives by Hub researchers added 217 new records to the IWC database, 76 for Australia. The latter were added to the Australian Marine Mammal Centre's national vessel strike database, providing new insights on historic rates of vessel collisions.

Australian strikes were estimated to account for 17% of known global incidents since records began. In records of Australian collisions where the species could be identified, the majority involved Humpback Whales (52%), followed by Southern Right Whales (12%) and Sperm Whales (7%). Based on 95 reports in which the fate of the whale could be reliably determined, 52% of strikes were considered fatal; 23% were injuries or probable injuries; and in 25% of cases the whale was unharmed. Reporting rates appeared to rise considerably in the late 1990s.

Maps of shipping density for larger vessels were generated from processed Automated Information Systems tracking data. The positions were translated into the distance-traversed by vessel and summarised for grid cells of 30 degrees. Data from a Hub survey of boat registrations, boat ramps and marinas were used to generate Australia's first national map of recreational boat density (smaller vessels relevant to coastal species such as Dugong and turtles). Aerial surveys, satellite tagging and other sightings data were used in distribution and habitat models to map coastal densities of Humpback Whales, Southern Right Whales, Sperm Whales, Dugongs and Green Turtles. This included devising a new method of interpreting tag movement data. The vessel density maps (categorised by size and speed) and species density maps were combined to provide the first national maps of relative vessel strike risk for Australia.

The new data management, modelling and mapping framework provided a vehicle for targeting and testing mitigation options such as changes to vessel routes. For example, vessels near Exmouth, Port Hedland, Dampier and Broome present a relatively high risk of collision for Humpback Whales. Mapping for the southern Great Barrier Reef showed which vessel types may encounter whale groups such as mothers and calves, and how risk changes over time at certain locations.



Shipping noise

The shipping noise study reviewed the numbers, types and movements of larger cargo, passenger and tanker vessels and quantified their acoustic signatures. These were sourced from Integrated Marine Observing System platforms, and an acoustic array installed for two months off Fremantle, Western Australia. Australia's Exclusive Economic Zone (EEZ) was classified into 28 acoustic zones according to 'sound environments' shaped by depth, oceanography and geology. Cumulative noise was modelled and mapped across the EEZ by combining the sound environment and ship noise signatures for each zone. Wind-driven noise was quantified to distinguish shipping and shipping noise from natural, background levels. The areas of highest shipping noise were North-western Western Australia, eastern Victoria and New South Wales, and the Great Barrier Reef.

To evaluate the potential impact of sound exposure levels, noise maps can be overlaid with species distribution maps, or with protected places such as Australian Marine Parks. A case study divided the Great Barrier Reef area into smaller acoustic zones to enable fine scale noise modelling. The resulting maps were used to identify higher risk areas for eastern Australian Humpback Whales. A second case study recommended passive acoustic monitoring in Beagle Marine Park to acquire useful vessel estimates in shallow water, and monitor whales, dolphins and fish. Noise arising from recreational vessels is an additional area of concern, particularly in shallow reef habitats such as the GBR World Heritage Area. A review of existing data concluded that measurements would need to span a wide range of speeds, due to high levels of noise variability.

FURTHER INFORMATION

david.peel@csiro.au

Final report

Outcomes and next steps

This project provided government, industry and researchers with a shared understanding of the risks associated with vessel strike and underwater noise. Management agencies have a framework for quantifying risk, targeting research, and comparing mitigation strategies that minimise disruption to shipping. Information was provided to review and implement the *National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna*. New global records of ship strikes were presented to the International Whaling Commission Scientific Committee and contributed to State of the Environment reporting.

Shipping noise can now be included as a pressure in marine spatial management, with a framework for national risk-mapping, and predicting the acoustic consequences of changes in vessel traffic and proposed developments such as port expansion. The work provides a pathway for assessing and managing risks to large marine animals, and adopting measurements and guidelines that meet international standards. Further progress will require:

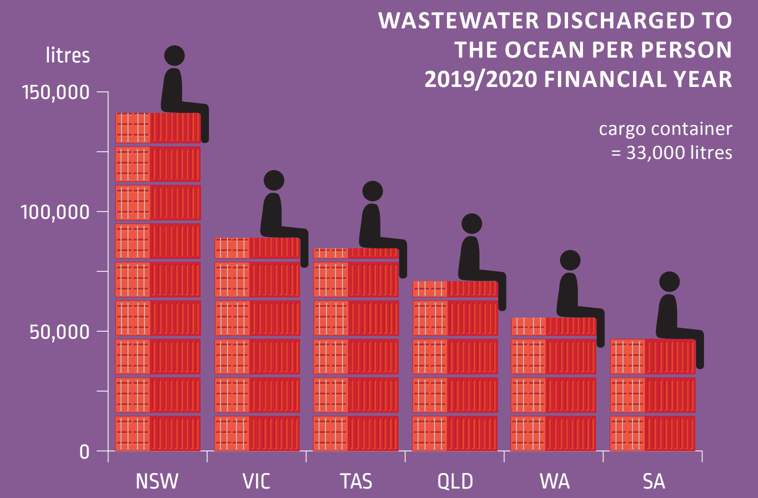
- validation/calibration of maps using sound loggers;
- an expanded database of ship noise signatures for use in sound propagation models, meaningful noise exposure criteria to assess impacts of underwater noise on marine animals;
- noise models focussed on frequencies perceived by animals of interest;
- increased efforts into dynamic species and noise model assessments to improve adaptive spatio-temporal management; and ultimately
- a cumulative noise framework that incorporates multiple noise sources.

First national outfall database marks a sea change in wastewater reporting

Much of the wastewater generated by Australia's coastal population is released to the marine environment. This practice, if poorly managed, can be detrimental to coastal ecology and biodiversity, as well as the health of water users.

Australia's wastewater treatment plants are required by environment protection authorities to monitor discharges near outfalls, but approaches vary across states, jurisdictions, regions and localities. Consolidated, reliable, public reporting was needed at a national scale so that water authorities, policy-makers and communities can evaluate the relative impacts, technologies, costs and opportunities associated with wastewater treatment.

In this Hub project, researchers worked with Clean Ocean Foundation to build a collaborative information sharing network among governments, water authorities, researchers and communities. It was the first attempt in Australia to provide all stakeholders with ready access to quality coastal wastewater data, consolidated at a national level. The National Outfall Database (NOD) provides a transparent evidence base for considering risks and investments in sewage infrastructure and wastewater recycling, a model for standardised, national reporting, and an avenue for community engagement in water quality monitoring.



Annual discharge would fill 1.9 Sydney harbours

The total volume of wastewater discharged from 194 Australian ocean outfalls in 2019/2020 was 957 gigalitres: equivalent to 1.9 Sydney harbours. The potential value of this water would have been more than more than $1 billion, had as little as 20% been recycled (based on $1.95/kilolitre recycled water charge by Victoria's South East Water).

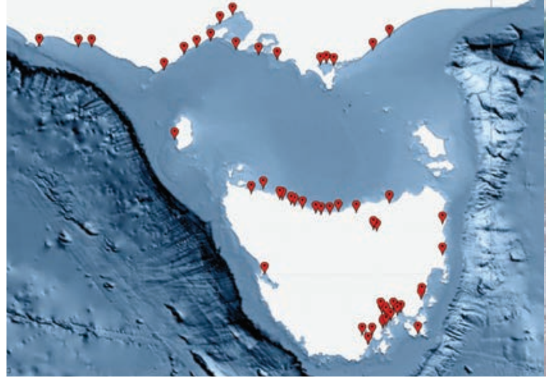
Annual wastewater discharge per person ranged from more than 550,000 litres in Victoria to more than 2000 litres in Tasmania. Nitrogen discharges ranged from nearly 4000 tonnes in Victoria to more than 170 tonnes in Tasmania, and phosphorus discharges ranged from more than 1500 tonnes in Victoria to less than 40 tonnes in New South Wales.

Approach and findings

The project team worked with 42 water authorities, and state, Northern Territory and local governments, to develop agreements and standard protocols for collecting and publishing discharge data. The resulting NOD website presents a national inventory of 194 coastal outfalls that users can search by location, or browse via an interactive national map, or by state and locality. Tables and charts summarise monthly discharges by volume and composition, including pollutants (oil and grease, *E. coli* and enterococci) and nutrients (nitrogen and phosphorus).

A *National Outfall Database Ranking Report* for 2018–2019 compared outfalls by total flow volume and nutrient load. Total nutrient load from individual outfalls in the 2018–2019 financial year ranged from 6.4 kilograms to 10,037,573 kg, with a mean of 319,333 kg. Outfalls with the lowest loads were more prevalent in regional areas and those with higher nutrient loads principally occurred in major cities.

Stakeholders involved in wastewater treatment, disposal, recycling, research and economics, as well as coastal community groups, were surveyed for their perspectives on reporting procedures. Water authorities supported transparency and national, centralised data collection, with a strong preference for reporting on parameters monitored under existing licensing criteria.



Detail from the National Outfall Database map showing outfall locations in southern Victoria and Tasmania. Image: Australian Ocean Data Network

Project leader John Gemmill of Clean Ocean Foundation (right) exchanges a monitoring kit with Brendan Donohoe of Surfrider Northern Beaches. Members of Surfrider Northern Beaches worked on a citizen science protocol for monitoring water quality near Sydney's Warriewood outfall. Image: Ruby Gemmill/Clean Ocean Foundation

Reporting on additional parameters would depend on the costs and benefits, based on evidence of the impacts to receiving waters. There was good support for collaborative development of a national report card.

Clean Ocean Foundation initiated a network of recreational water users interested in helping to understand their water quality issues and engage in solutions. Sydney and Gold Coast coastal groups developed 'citizen science' protocols for water-quality monitoring. Other communities were assisted to find information about local outfalls and contact like-minded coastal groups.

Outcomes and next steps

The NOD demonstrated a procedure for national, public reporting of outfall monitoring data underpinned by community involvement, scientific rigour and cross-government support. Water authorities, governments, policymakers and communities have a transparent evidence base to understand outfall dynamics and impacts at the local, regional and national scale. This provides unprecedented capacity for discussion and decision-making about risks and investments in sewerage infrastructure, wastewater recycling, and standardised national reporting.

Communities are better informed about sewerage outfalls in their area, and have a pathway to becoming involved in local monitoring through citizen science. Community groups, researchers and journalists have used the NOD as a trusted information source on outfall discharges, including their potential association with Covid-19 transmission and shark interactions. Water authorities benefit from community engagement and shared understanding of infrastructure constraints and funding priorities. Commercial interests have access to information on the location and composition of waste water streams for recycling for industrial, agricultural or residential development.

NOD data underpinned *Coastal Outfall System Upgrades in Australia: Benefits, Costs, and Improved Transparency*, an external report that examined the economics of upgrading Australia's coastal outfalls to a tertiary level to produce recycled water for non-drinking purposes, providing opportunities for reduced disposal to the ocean. Net benefits were estimated at $22 billion to $52 billion, with upgrade costs of $7 billion to $10 billion. This suggests such upgrades are economically desirable, even without the added environmental, health and social benefits.

Survey results from this project provide a basis for engaging stakeholders in developing a national reporting standard. A pilot approach is recommended to developing guidelines for understanding and managing risk associated with emerging contaminants such as plastics, cosmetics and therapeutics.

FURTHER INFORMATION
johng@cleanocean.org
Towards national standards for outfall data
marcus.haward@utas.edu.au
Primary microplastics in the marine environment

What about intentionally added microplastics?

Intentionally added microplastics are tiny particles that add qualities such as elasticity, strength or colour to products. Some of these particles wash away with use, with little-known impacts on marine ecosystems. A Hub study explored the scale, sources, pathways and impacts of personal care and cleaning products (PCCPs), microfibres, tyres, fertilisers, biosolids and wastewater treatment in Australia, as well as policy options. Working with the Department of Agriculture, Water and Environment, they sought the views of policy-makers, researchers and industry peak bodies. They also reviewed relevant European Union and United States research and policy development.

Microfibres emerged as the most common known microplastic pollutants in the marine environment, but the fate of tyre wear, the second most abundant microplastic, was poorly understood. There was a lack of quantitative data for every major source and pathway of microplastics, and scant research on the effectiveness of mitigation and management. Solution-focused research should therefore be a high priority, including studies of consumer attitudes and behaviour. A key development would be an extended circular economy response designed to reduce, reuse, repurpose and recycle plastics. Such initiatives engage closely with industry as they involve changes in not just manufacturing and packaging, but also significant modifications in design and materials.

Commercial fishing peaked in Australia in the early 2000s. Image: Chris King/Unsplash

Charting decades of marine pressures

Understanding the values associated with the marine environment, and the pressures that act on those values, is important to effective biodiversity conservation and sustainable resource use.

This challenge is considerable, given the diversity of values and pressures, and their complex interactions in different parts of the marine environment.

This Hub project addressed the need for a national approach to collating, analysing and presenting pressure data, and finding where cumulative pressures pose the greatest risk.

FURTHER INFORMATION

piers.dunstan@csiro.au

Changes in pressures on the marine environment

Guidelines for analysis of cumulative impacts and risks to the GBR

Cargo shipping increased significantly in 1999–2015. Image: Borderpolar Photographer/Unsplash

The resulting overview of changes in cumulative pressure provides a lens for determining how and why the marine environment has changed; which areas are subject to many pressures; and the potential local and national impacts of marine activities.

Approach and findings

Historical pressure data were collected and mapped for all Australia's marine regions (Temperate-East, South-East, South-West, North-West and North) to produce a coherent understanding of the major sources of pressure and how they have changed in the past 30 years. Cumulative pressure was calculated across seven activities: fisheries, anthropogenic ocean noise, oil and gas production, oil spills, shipping, sea-surface temperature and population.

The overall conclusion was that pressures in the Australian EEZ are changing in ways that are often not predictable. Increased cumulative pressure was especially evident in the South-west Marine Region due to increases in some fisheries, ocean noise, and climate change. Rising sea-surface temperature in this region adds additional stress. Key ecological features such as Perth Canyon and Western Rock Lobster, and biologically important areas for multiple species of seabirds, Southern Right Whales and Sperm Whales may be vulnerable. In all other marine regions there were increases in many combinations of pressure and climate change.

Declines in total cumulative pressure for the North and North-West region masked increases in oil and gas production and marine vessel activity. This highlights the need to identify specific combinations of pressure and value in order to estimate potential impacts and risks, and that cumulative impact can be significant in areas of increasing multiple pressure.

Fisheries: Summaries of fishing effort generated from Australian Fisheries Management Authority logbook data showed Australian commercial fishing expanded from the early 1980s, with establishment of the Australian Exclusive Economic Zone. Domestic trawl and long-line fisheries peaked in the early 2000s, then declined following the adoption of formal harvest strategies by the South East Trawl fishery in 2006.

Anthropogenic ocean noise: Seismic survey transects summarised by area highlighted extensive surveying of the Australian shelf, slope and abyss since the 1960s, peaking in the 1990s on the North West Shelf. The period of extensive seismic surveys is followed by development of oil and gas infrastructure.

Oil and gas production: Records of oil and gas rig locations, and oil pollution events, were compiled from Australia's National Offshore Petroleum Titles Administrator and the Australian Maritime Safety Authority. They show early oil and gas development primarily in the South-east Marine Region, with the North-west Marine Region being developed in the 1990s. Oil and gas well drilling is much greater in the North-west than in any other marine region.

Oil spills: Oil-spill pollution events between 1970 and 2016 were concentrated around major ports in the Temperate-East, South-east and North-West regions.

Shipping: National ship reporting systems showed the Temperate-East Marine Region had the largest proportion of vessels for most of 1999–2015. Shipping in the North-west Marine Region exceeded the Temperate East for the first time in 2012, due to increased mineral, oil and gas exports. Dense vessel aggregations were visible at individual wells. Cargo vessels on coastal or international voyages in 1999–2015 increased from 3291 to 5475 ships.

Population: Coastal population growth was calculated from Australian Bureau of Statistics data. Australia's population increased from 17.28 million in 1991 to 22.34 million in 2011, with most growth in coastal areas. The Temperate-east, South-east and South-west increased at approximately the same rate, and the North-west showed a significant increase in population since 2006. This corresponded to increased marine shipping activity and oil and gas production.

Sea-surface-temperature: Change in sea-surface temperature was estimated from satellite observations and validated with data from long-term monitoring stations and the global drifter program. Clear trends were associated with oceanographic features and average warming was greatest off southern Western Australia and eastern Tasmania.

Outcomes and next steps

Pressure data collated in this project were provided to web portals including the Australian Ocean Data Network, Seamap Australia and data.gov.au to make available to the public. They were also provided to the Australian Department of Agriculture, Water and the Environment for integration into internal information systems. Five-year summaries were tailored for national State of the Environment reporting.

Summaries for the South-east Marine Parks Network were used in the pilot management effectiveness system developed jointly by the Hub and Parks Australia (see story on page 24). Pressures will need to be updated to provide input into the Australian Marine Park review process. Due to the absence of information linking pressures and values, the status and trends of biodiversity that may be impacted remains unclear.

Guidance for assessing cumulative impacts on the Great Barrier Reef

The Great Barrier Reef (GBR) is impacted by many pressures including climate change and direct and indirect human activities. The *Reef 2050 Long Term Sustainability Plan* aims to ensure cumulative impacts are managed below threshold levels, to protect the GBR's Outstanding Universal Values. These include coral reefs, seagrass meadows, mangrove forests, sharks, seabirds, dugongs and dolphins. Calculating the cumulative impacts of pressures such as coastal development, pollutants, fisheries, cyclones and climate change is a major challenge for reef managers.

A Hub study provided a systematic and consistent approach to estimating cumulative risk and impacts in the GBR, and tailored summaries for users including the GBR Marine Park Authority, Queensland Government and Commonwealth Department of Agriculture, Water and the Environment. The guidance is intended to be applied at a regional or plan of management level, and at a development application level, within a standard risk assessment framework. It details the necessary concepts and takes a stepped approach to linking multiple pressures, impacts and values, and selecting appropriate analytical methods or tools.

A case study for the *Whitsundays Plan of Management* assessed cumulative impacts for coral reef ecosystems in the GBR, and included reefs around Hayman, Arkhurst, Langford, Black, Bird and Hook islands. Assessed pressures included coral bleaching, cyclonic storms and Crown-of-thorns Starfish (COTS) outbreaks; and impacts from boat anchor damage, recreational fishing, and fin damage from snorkelling and scuba diving.

An ecosystem model representing the direct effects of pressures found impacts from recreational use alone ranged from relatively low levels of likelihood where use and activity levels are most restricted, to relatively high where use and activities levels were greatest. The inclusion of climate change and COTS outbreaks dramatically increased the likelihood that reef values could be diminished throughout a majority of the area of assessment.

Image: David Clode/Unsplash

A deeper, national understanding of shallow reef biodiversity

Reliable, understandable information about Australia's marine biodiversity and the impact of pressures such as climate change, fishing and pollution is vital to national and international reporting, and the management of marine protected areas.

In the past, however, national assessments of shallow coral and rocky reef biodiversity were based on expert opinion, or detailed studies in focus locations, thus limiting our capacity to determine the most substantial and widespread issues.

Hub projects harnessed and standardised new and long-term shallow-reef monitoring datasets to assess biodiversity state and trends. The combined dataset extended the breadth and resolution of shallow reef biodiversity monitoring, providing a comprehensive and unique resource that yielded the first national view of climate change impacts, and indicators of ecological change.

Approach and findings

The national shallow reef biodiversity dataset was compiled from three existing monitoring programs spanning all coastlines:

- Reef Life Survey (RLS), conducted since 2008;
- the Australian Institute of Marine Science Long-Term Great Barrier Reef Monitoring Program, initiated in 1983; and
- the Australian Temperate Reef Collaboration Program (including Parks Victoria subtidal reef monitoring), conducted since 1992.

The programs involve divers censusing a standardised area beside transect lines to collect local details on the abundances of individual species of fish, mobile invertebrates, corals and kelp cover. As a result, specific indicators could be used to analyse trends in local ecological responses to individual pressures. This is a step forward from relying on coarse measures of reef health subject to multiple pressures, which can be difficult to interpret. For example, rather than providing a general assessment of live coral cover, RLS imagery collected before and after mass coral bleaching events in 2016 and 2017 was identified to species level. This offered new opportunities to determine species-level impacts, and changes in the ecological make-up of coral reefs.

Climate change: Analysis of the national shallow reef biodiversity dataset identified the significant national impact of climate change on marine biodiversity. This was evident through the direct effects of temperature changes on reef species, and through habitat degradation caused by marine heatwaves and coral bleaching.

Habitat-forming organisms such as corals and kelps experienced variable changes over time, including widespread, yet patchy, coral mortality in response to marine heatwaves on the Great Barrier Reef, North West Shelf and throughout the Coral Sea. This disproportionately affected members of the genus *Acropora,* but overall impacts depended heavily on the state of the coral community before the heatwaves. Reefs with low cover of more sensitive coral species experienced less change. Change in kelp cover was low at many monitoring locations in south-eastern Australia, but showed a moderate rebound at Jurien Bay, WA, after the 2011 heatwave, and small increases at Encounter Marine Park, SA, and elsewhere.

TOP: **A Reef Life Survey diver contributing to the effort to keep a detailed log of change in Australian reef systems.** Image: Rick Stuart-Smith, Reef Life Survey

Importantly, the magnitude of change to tropical coral reef fishes caused by heatwaves was not as large as that experienced by reef fishes in temperate areas. The footprint of warming sea-surface temperatures on reef fishes was evident nationally during the past decade (2010–2020), but rapid tropicalisation in fish community structure was particularly clear in south-eastern Australia.

Fishing: Previously identified declines in large fish biomass in response to fishing pressure appear to have slowed down, although this could be partly influenced by a greater focus of the long-term monitoring programs on marine protected areas and nearby sites.

Pollution: Additional survey data were obtained on reef biodiversity and pollutants near the coastlines of Adelaide, Melbourne, Hobart and Sydney. Microplastics were ubiquitous in sediments at all sites sampled across south-eastern Australia (Sydney to Adelaide) and Tasmania. Heavy metals and proximity to ports showed the strongest relationships to the distribution of sessile reef biota after accounting for natural environmental gradients in urbanised embayments.

TOP: **The composition of corals before marine heatwaves was important to determining overall coral mortality following coral bleaching events.** Image: Rick Stuart-Smith, Reef Life Survey

BELOW: **Temperate reef fish communities showed the largest responses to marine heatwaves.** Image: Rick Stuart-Smith, Reef Life Survey

Outcomes and next steps

This research provided new and detailed national data and analyses for national and international reporting. The data were central to assessing long-term marine and coastal biodiversity trends for Australia's *State of the Environment report 2021*. Two ecological indicators – developed to assess the effects of ocean warming and fishing pressure – are applied globally by the Biodiversity Indicators Partnership, including to assess progress towards Sustainable Development Goals and Convention on Biological Diversity goals by member nations.

The data also contribute to the monitoring of marine protected areas, including under Parks Australia's management effectiveness system. Further, targeted analyses of the rich national coral dataset will explore community-level changes and ecological drivers of change at offshore reefs across Australian Marine Parks.

FURTHER INFORMATION

graham.edgar@utas.edu.au
rick.stuart-smith@utas.edu.au

Continental scale threats – Indicator Report
National reef biodiversity assessment

2

SCIENCE FOR SUSTAINABLE USE

Evaluating approaches to monitoring recreational fishing in Australian Marine Parks

Recreational fishing is a popular activity in Australia's state and Commonwealth waters, including in Australian Marine Parks (AMP) managed by Parks Australia (PA).

As more fishers venture offshore, managers need to understand how fishers are using these AMPs: when they visit, where they go and what they catch. For some commercial species the recreational catch has a bearing on harvest strategies administered by the Australian Fisheries Management Authority (AFMA). This includes transboundary stocks such as Southern Bluefin Tuna.

A national baseline for recreational fishing was established in 2000/01. Since then, most states have continued statewide or regional surveys, but these have not been nationally consistent in frequency or timing. Australia therefore lacks a time-series of coordinated national statistics for recreational fisheries. This Hub project established a network for state and national agencies to share data and assess trends and impacts, and assessed survey approaches for their potential to gather relevant information.

Approach and findings

Hub researchers scoped and implemented this project together with two state agencies – the Western Australian Department of Primary Industries and Regional Development, and the New South Wales Department of Primary Industries – as well as with managers from AFMA and PA. Joint workshops facilitated the sharing of state datasets for analysis, and established a network for ongoing collaboration.

WA and NSW recreational fisheries were used as case studies for the assessment of existing state-based approaches. State-wide survey data covering shore and boat-based recreational fisheries, and logbook records from charter boat and tournament game fisheries, were assessed for their value to PA and AFMA. In Tasmania, a survey, low-cost sensor and predictive modelling method was trialled at a boat ramp near Freycinet Marine Park. The survey identified fishing locations, and views of recreational fishers on the management, values and uses of offshore areas. Trailer boat movements on ramps across 24 hours

MAIN IMAGE: **Recreational fishers launching at Tantabiddi boat ramp, Ningaloo, WA.** Image: Jason Mazure, Mirage Digital

INSET TOP: **Recreational fishing survey data were assessed for their value to assessing trends and impacts.**

ABOVE: **A low-cost sensor method was trialled at a Tasmanian boat ramp near Freycinet Marine Park.** Image: CSIRO

and multiple days was also observed using trail cameras, and, at one site, closed circuit television. Ramp use data were modelled with weather observations from adjacent Bureau of Meteorology automatic stations to predict fishing metrics such as trip numbers, launch and retrieval patterns and trip durations.

The state-based recreational fishing surveys varied in their ability to meet all the research needs of the Commonwealth agencies, but demonstrated a well-established framework of expertise, data collection, sampling design, analysis and innovation. For example, the WA approach (with some caveats) provided reasonable estimates of recreational fishing effort and catch for Ningaloo Marine Park (Commonwealth Waters). This was not possible from the NSW data for the Hunter Marine Park, however, due to a relatively lower level of sampling in NSW compared to WA at regional scales. Neither database could determine distributions of recreational fishing effort or catch within AMPs at the scale of zoning.

The charter boat fishery, however, may provide a useful proxy for monitoring the spatial aspects of general demersal recreational fisheries in AMPs. The composition and distribution of catch in particular is at relevant spatial scales, and the frequency of reporting is much higher than the state-wide assessments.

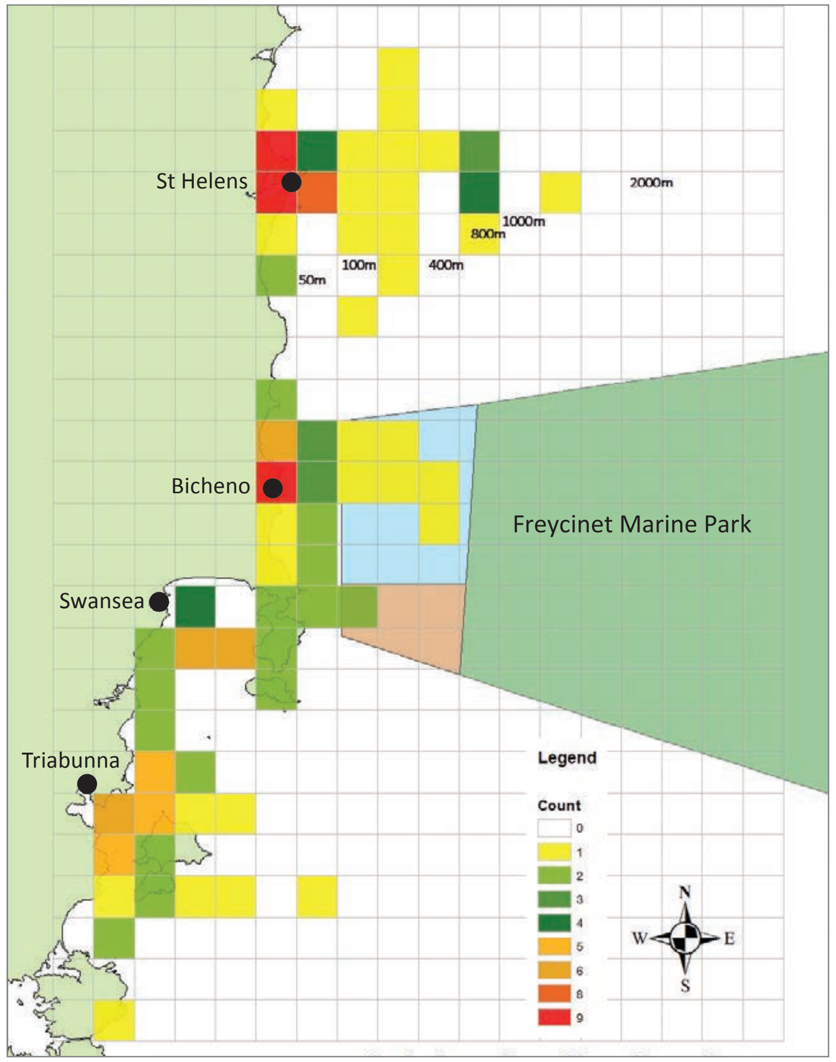
Off-site surveys are of most use at high levels of assessment, such as the division of catch between Commonwealth and state waters, or at the park or AMP network scale. On-site methods are a better option for more detailed information needs, such as at the scale of park zoning, or for specific recreational species. Aerial surveys and potentially satellite surveys could also be used to investigate small scale distributions of fishing effort.

The boat ramp survey near Freycinet Marine Park found that fishers' knowledge about the park was poor, but generally they strongly supported various marine park biodiversity and sustainability objectives. Nearly all trailer boat effort both observed and reported from the season in the park originated from one boat ramp. Furthermore, their reported distribution of fishing effort showed no use of restricted zones.

FURTHER INFORMATION

tim.lynch@csiro.au

Comparing fisheries research and its application to management



Distribution of recreational fishing effort in grid squares of four nautical miles for 50 fishers interviewed at four boat ramps off coastal Tasmania in December to April of 2017 and 2018. Nearly every coastal grid square had been fished by the group as a whole.

The new, low-cost technique to sample activity at high-traffic boat ramps combined with weather observations and modelling showed potential to generate accurate predictions of recreational fishing effort. In particular, automatic weather station data correlated with patterns of trailer boat launch, retrieval and trip durations.

Outcomes and next steps

This project generated an improved understanding of marine recreational fishing in selected areas of Australia's Exclusive Economic Zone, and the potential for state surveys to provide information of value to managers of AMPs and Commonwealth fisheries. PA and AFMA are now better positioned to work with the states to assess future trends in recreational fishing.

PA was provided with the first ever analysis and reporting of state data showing how recreational fishers use Ningaloo Marine Park (Commonwealth Waters) and Hunter Marine Park. AFMA was provided with a deeper understanding of selected commercial species affected by recreational fishing, and the implications for fishery harvest strategies. For example, recreational catches of flathead and school sharks were at levels requiring explicit consideration in stock assessments.

Continued evolution of state-wide survey methods would be beneficial, particularly where there are multiple stakeholder and jurisdictional interests. National coordination to temporally align state surveys would add value to existing approaches. For specific AMPs, periodic ramp-based sensor data and interviews, calibrated with automatic weather station observations, could provide near real time estimates of recreational fishing effort.

2

LEFT AND BELOW: **Rachel Przeslawski participating in field surveys.** Images: Schmidt Ocean

Steering clear of oranges and apples

In October 2019, Hub research leader Rachel Przeslawski, formerly of Geoscience Australia, seized the chance to revisit a deep hole in the seafloor of Wessel Marine Park.

Unusually for this part of northern Australia, the hole plunged to depths of 115 m. Earlier surveys hinted it might host rich seafloor communities. This was the perfect place for Dr Przeslawski to indulge her interest in understanding marine invertebrates and the environments that shape them, while maximising the value of marine data. These challenges engage her impressive talent for making connections, and simultaneously zooming in and zooming out.

"Growing up in Michigan, I didn't see the ocean until I was 11 years old – something unusual for most Australians!," Dr Przeslawski says. "I remember walking along the Atlantic coastline after heaps of sand dollars had washed up and trying to figure out the reason. I suppose that was the start of trying to make connections between marine invertebrates and potential stressors."

Decades later, Dr Przeslawski and her colleagues zoomed in on the Wessel hole, from the Marine National Research Facility Research Vessel *Investigator*. They used multibeam sonar to map the seafloor, and a towed video system to collect visual samples from the deep hole and neighbouring habitats.

"We were excited to see dune ridges apparently dating back 12,000–8,000 years, a time of lower sea level," Dr Przeslawski says. "As in many other offshore areas around Australia, this remnant coastline provides a platform for suspension feeders such as corals and sponges. These form habitat for other animals such as crinoids, brittle stars, skates and fish, all grappling against a barrage of tidal currents."

The new understanding of this ancient seafloor feature highlighted its cultural importance to the Marthakal, Dhimurru and Laynhapuy people. Ultimately it will contribute to decisions about setting priorities and baselines for monitoring across the Northern Marine Parks Network, and evaluating management goals. But it only has value for this purpose because the survey team had zoomed in while zooming out. They applied and promoted best practice methods defined in the Hub's *Field Manuals for Marine Sampling to Monitor Australian Waters*.

Dr Przeslawski co-led the Hub team that developed the field manuals, which apply to common marine sampling platforms. "Using the best practices means that data from surveys such as Wessel can contribute to national datasets, and will be comparable in time and space with data collected elsewhere around Australia," Dr Przeslawski says. "Rather than comparing apples with oranges, we'll be able to look at larger-scale regional and national patterns, identify places of high natural value, and understand the impact of pressures we place on the marine environment."

As well as orchestrating the involvement of Australia's marine research community in developing the manuals, Dr Przeslawski helped to steer their promotion and uptake. This occurred through her roles as president of the Australian Marine Sciences Association and a member of the Ocean Best Practice Steering Group, an initiative coordinated by the Intergovernmental Oceanographic Commission of UNESCO.

Best practice sampling also supports management tools such as predictive modelling. Much of Dr Przeslawski's work with the Hub involved characterising invertebrate life across Australia's north and north-west, including in Oceanic Shoals and Gascoyne Marine Parks. Using survey data for polychaetes (bristle worms) and sponges, the modelling gave resource users and managers a broad overview of natural values in areas yet to be explored.

"Our best practices have been quietly percolating through various national and international marine science programs, and it's become clear that the highly collaborative and iterative approach we used to develop them has become a best practice itself!" Dr Przeslawski says.

"I've have been involved with the Hub and its previous iterations for almost 15 years and have developed a strong network of marine scientists and managers. Their diversity of experience, expertise and personalities helped me keep a flexible and priority-driven approach, and to enjoy my work.

"Much of what we do on these surveys is pure discovery – new species, new habitats, new features – and this generates a strong camaraderie and shared excitement for what we may find."

3

Indigenous engagement, partnerships and participation

Malak Malak Rangers Amos Shields and Aaron Green on the Daly River. Image: Michael Lawrence-Taylor

Building Indigenous involvement in research through consultation, training and employment

Indigenous Australians have a growing interest in leading, partnering and participating in marine and coastal research to provide benefits for Indigenous people, including through training and employment.

The Hub provided national leadership to establish and promote respectful partnerships for research and monitoring on Sea Country. This included innovative collaborations with Indigenous organisations, communities and ranger groups, and with the Australian Marine Sciences Association (AMSA) (see story on page 53).

Indigenous engagement in research occurred across nine Hub projects. Regional projects identified and advanced Indigenous research interests and priorities and provided training and employment, particularly to recover threatened species and restore coastal habitats. Focus areas included seagrass, shellfish reef and giant kelp restoration; Sea Country mapping, Hammerhead Shark tagging and Largetooth Sawfish conservation. At a national scale, the Hub convened annual workshops to promote Indigenous partnerships in marine science, and conducted the first national-scale survey of how marine researchers engage with Indigenous communities (see story on page 52).

Additionally, the Hub commissioned Indigenous people to organise Indigenous workshops and prepare cross-cultural communication products. Artwork, videos, signage, handling protocols and reports communicated the findings of research on threatened species and habitat restoration.

Together these projects significantly increased the level of understanding and respect for Indigenous rights, interests, responsibilities and cultural values among Hub researchers and their stakeholders and collaborators. They also raised the capacity of Indigenous communities to provide leadership for managing Sea Country and to work in partnership with research and management institutions.

Hub researchers and Malgana Rangers working together on seagrass restoration at Shark Bay. Image: Elizabeth Sinclair, The University of Western Australia

Identifying priority species in the north

Research interests identified by Indigenous people reflect the powerful obligations as custodians of country and the lifeforms and ancestors that depend on their management of country. The Hub worked with the North Australian Indigenous Land and Sea Management Alliance to understand Indigenous priorities for threatened and migratory marine species in Northern Australia. While specific interests varied between Indigenous groups, marine turtles, dugong, shorebirds and seabirds, and sawfishes were of high importance.

Restoring wirriya jalyanu (seagrass) at Gathaagudu (Shark Bay)

Indigenous communities have demonstrated strong interests in research partnerships to restore coastal habitats. The Malgana Aboriginal Corporation at Gathaagudu (Shark Bay), Western Australia, developed co-led research with the Hub to restore wirriya jalyanu (seagrass) destroyed by marine heatwaves. Weetapoona Aboriginal Corporation worked with the Hub to shape research to restore giant kelp forests off Tasmania. In both cases Indigenous people identified their interests, contributed to research design, and advised on culturally respectful access to sites. Malgana Rangers were employed on a part-time basis and trained to collect seagrass seeds, seedlings and samples and apply nature-based restoration techniques to counteract the effect of heatwaves. See story on page 82.

FURTHER INFORMATION

peter.kyne@cdu.edu.au

Indigenous research and management priorities for threatened and migratory species

ian.mcleod@jcu.edu.au

Seven pearls of wisdom: advice from Traditional owners to improve engagement

Yuku Baja Muliku Ranger Mick Hale releases a shark after tagging. Image: Andrew Chin

Sage advice on partnering to restore shellfish reefs

At a Bribie Island workshop convened by the Hub, Traditional Owners from Australia and New Zealand identified Indigenous aspirations and collaborative opportunities for restoring shellfish reefs. Working with Hub researchers, they identified 'seven pearls of wisdom' to guide mutually productive partnerships between Indigenous people, research institutes, conservation groups and restoration practitioners. These included early and long-term engagement and project co-design and management; acknowledging Country and recognising Indigenous peoples' rights, responsibilities and knowledge; and linking coastal water quality with activities on land.

Restoring giant kelp in Tasmania

In Tasmania, the weetapoona Aboriginal Corporation advised Hub researchers about site-selection for giant kelp outplanting trials. This community has historical knowledge of local declines in giant kelp at Trumpeter Bay on the east coast of Bruny Island. They engaged with the project team to facilitate knowledge-sharing and the collaborative restoration of their Sea Country. Training of weetapoona Indigenous people in giant kelp restoration techniques will promote recovery and explore commercial aquaculture opportunities off southern Tasmania.

Mapping Sea Country

Wadandi Traditional Custodians partnered with Hub researchers and Parks Australia to assist in the design of biodiversity surveys for the management and protection of Australian Marine Parks in the Wadandi Watturu Boodja (Saltwater Country Land and Sea) off south-west Western Australia. The Wadandi Traditional Custodians were contracted to map their Sea Country, which helped researchers target features across the submerged landscape. The partnership also forged a better understanding of how traditional ecological and scientific knowledge can help manage parks and raise awareness of cultural connections to Sea Country. The ancient pathways of several rivers have carved channels through the rocky reef. One of these is located directly offshore from the mouth of the Margaret River. Traditional Custodians also joined researchers on surveys of ancient submerged coastlines across the Ngari Capes Marine Park and adjacent South-west Corner Marine Park (see story on page 20).

INDIGENOUS ENGAGEMENT, PARTNERSHIPS AND PARTICIPATION 3

Hammerhead shark tagging floats two-way learning

Hammerhead sharks hold strong cultural value for many saltwater Traditional Owner groups and their conservation aligns with Sea Country management priorities. A Hub project that explored how hammerhead sharks move through northern Australian waters (see story on page 62) engaged with Traditional Owner groups to share knowledge and facilitate training and participation in field research. The aim was to engage in a culturally respectful manner that recognised the interests, rights and Indigenous knowledge in land and Sea Country.

Rangers from the Yuku Baja Muliku (Cape York), Yirrganydji (Cairns) and Girringun (Cardwell) Traditional Owner groups were trained in shark tagging and handling and took part in tagging expeditions off Port Douglas, Dunk Island and the Hull River. There was a sharing of knowledge regarding Traditional values and scientific understanding of sharks and Sea Country, and rangers were engaged to locate satellite tags that washed ashore in their areas.

In their evaluation of the engagement, Traditional Owners were supportive, but advised that a more respectful approach would have been to talk to the owners of the country before setting up the project. They also advised that Traditional Owners have their own information needs, which increasingly are documented in contemporary management plans that recognise the importance of science as well as Indigenous knowledge. Indigenous rangers who took part in the tagging trips were excited to be involved and felt the research crew were supportive. Another meaningful outcome was the opportunity for two-way learning.

Reflections on the first national snapshot of Indigenous engagement in marine science

Australian marine scientists show positive aspirations to engage Aboriginal and Torres Strait Islander people in research.

Many scientists are unsure about where the responsibility for engagement lies, and what research is of interest to Indigenous communities. These are key findings of a Hub study that surveyed 128 marine scientists to understand how they had engaged with Indigenous communities during their research careers. The survey established a baseline for monitoring future changes in scientists' motivations, perceptions and practices.

ABOVE: **Marine Biodiversity Hub deputy director, Paul Hedge.**

Quandamooka woman Mibu Fischer of CSIRO.

The study team included Hub deputy director, Paul Hedge, and Ingrid van Putten, Cass Hunter, and Mibu Fischer of CSIRO. Here are their reflections on the survey, and the pathway to building respectful engagement to bring mutual benefits for researchers and Indigenous Australians.

Paul Hedge, Marine Biodiversity Hub

This study moves us beyond what we think is happening across Australia – based on our individual limited experiences, knowledge and biases – towards an evidence-based understanding of what marine scientists are collectively thinking and doing. It provides useful insights about where (often scarce) resources should be targeted to improve Indigenous engagement, and outcomes for both Indigenous communities and scientists.

For me, the survey points to the need for increased investment to minimise uncertainty about engagement. It is also important to reward researchers who engage for the life of a project and beyond, rather than just to access field sites or support data collection. Engagement at the start of a project is critical for conceiving and agreeing on the benefits that will flow from research. Engagement at the end is critical for reflection, learning and building enduring relationships.

We are seeing increased levels of professionalism across marine research institutions for engaging Aboriginal and Torres Strait Islander people. Future surveys of this type, including collection of similar information from Indigenous communities, will be important for confirming whether the right types of changes are happening.

Mibu Fischer, CSIRO, Quandamooka woman

The majority of survey respondents indicated they preferred to learn about culturally appropriate engagement from discussions with experienced research colleagues or Indigenous people. Less than a third used Indigenous community engagement protocol documents to develop their understanding. It would be interesting to know why these documents were not widely embraced.

I would like to see engagement as integral to marine research. Building relationships with Indigenous communities is essential, even in situations where the link is obscure. All staff members, supported by research leaders, have the responsibility to be respectful, inclusive and welcoming of a new way of working. Everyone should be encouraged to join activities happening in this space.

Funding and research bodies need to change processes to include engagement, to extend timeframes to allow for proper engagement and relationship building, and to adequately support and remunerate Traditional Owners who participate. As scientists we also need to be aware of the pressures we place on under-resourced and over-extended communities. This is likely to escalate with the increasing understanding of Indigenous connections to offshore environment, such as sacred sites that were covered from historic sea-level rise.

FURTHER INFORMATION
paul.hedge@csiro.au
Perceptions, motivations and practices for Indigenous engagement

ABOVE: **Kuku Yalanji and Maluiligal woman Cass Hunter of CSIRO.** Image: Leigh Harris
ABOVE RIGHT: **Ingrid van Putten of CSIRO.**

Cass Hunter, CSIRO, Kuku Yalanji and Maluiligal woman

Developing the survey was not straightforward. As an Indigenous researcher I wanted to ensure we were asking useful questions, given engagement is core to building respectful partnerships. I began to realise that efforts to pinpoint an issue are complicated by the many factors affecting perceptions, motivations, and efforts to resolve misunderstanding.

I found it surprising and encouraging that many survey respondents did not avoid engagement, given its complexities. I hope this positivity persists as the marine sector strengthens its capacity to conduct science with cultural integrity. We need to end the perception that the main responsibility for engagement rests with Indigenous practitioners. Team commitment, and relationships built on trust and willingness to listen, learn and respond will be key to progressing respectful engagement.

I think it is good for senior managers and staff to reflect on what respectful and successful engagement looks like. Authentic efforts to listen to Traditional Owners, and to openly discuss experiences and challenges, creates opportunities to cultivate practices that are respected by Aboriginal and Torres Strait Islander communities. Building science with cultural integrity does not happen by chance, it needs real long-term commitment. Research institutions may need to invest in further capacities and Indigenous roles in their organisation to strengthen the level of due diligence.

It is important for the marine sector to understand that co-designing science involves more than holding a participatory workshop. Co-design replaces top-down hierarchies with willingness to work together on an equal platform as this respects the knowledge, views and preferences of Traditional Owners. It is about the genuine willingness of parties to fairly shift their behaviour and practices when ideas stretch them beyond the business-as-usual approach.

Ingrid van Putten, CSIRO

The study highlighted to me the importance of capturing the voices of social and interdisciplinary scientists, who were under-represented in this survey. Natural scientists are relatively easy to target through existing professional organisations. This suggests there may be a need for social and interdisciplinary scientists to form knowledge groups with a focus on marine science.

I was heartened to see that more than a third of respondents thought the whole project team is responsible for engagement. In my mind it makes sense for everyone to have the insights, knowledge, and training on how to engage well, regardless of their level of participation.

The survey identified the top motivation for engagement with Aboriginal and Torres Strait Islander communities was to seek mutual benefits for research and Indigenous communities. I was surprised to learn after the survey, however, that we have no idea whether the benefit is indeed mutual. As scientists we publish in peer-reviewed literature that is ill-equipped to capture non-scientific (alternative) voices. I think we need to critically examine the way we do business as scientists and reflect on alternative ways to balance voices, stories, and narratives in our scientific 'end-products'. I hope to see more opportunity to straddle the bridge between marine science and Indigenous knowledge, and that researchers can lead the way to finding mutual benefit in marine research and ensuing publications.

INDIGENOUS ENGAGEMENT, PARTNERSHIPS AND PARTICIPATION 3

AMSA workshops a forum for national engagement

The Hub brought together Indigenous organisations and AMSA to convene five annual Indigenous engagement workshops that promoted Indigenous partnerships in marine science. Successive workshops took place at Wellington, New Zealand (2016), Darwin (2017), Adelaide (2018), Fremantle (2019) and Sydney (2021).

The workshops raised the profile of Indigenous engagement in marine research by showcasing collaborative projects and sharing information and perspectives. Topics included Indigenous Sea Country rights and aspirations, successful research partnerships, lessons learned, and the importance of culturally appropriate engagement based on accepted standards.

The workshops significantly improved understanding and capacity in Australia's marine science community about the importance of Indigenous engagement and how to do this in a culturally appropriate and respectful way. They identified opportunities for advancing regional approaches to Sea Country research and management in Western Australia, and for a partnership between the Western Australian Marine Science Institution and the Malgana Aboriginal Corporation. They also helped to advance AMSA's approach to Indigenous inclusion in its annual workshop, the primary mechanisms that AMSA uses connect with Australian marine researchers.

As knowledge and experience was gained, the workshops were increasingly organised around an Indigenous-led agenda to ensure they reflected that needs and interests of Indigenous people in the regions where workshops were convened.

Working together to conserve Largetooth Sawfish in northern rivers

In an enduring partnership, Marine Biodiversity Hub researchers and Indigenous rangers shared knowledge, performed research and rescues, and promoted sawfish conservation.

FURTHER INFORMATION
peter.kyne@cdu.edu.au
Malak Malak sawfish patrol and relocation protocol

Hub researchers Peter Kyne and Christy Davies with Malak Malak, Yugul Mangi and Numbulwar Numburindi Amalahgayag Injung Rangers in the Roper River region, NT. Image: Ruth Leeney

The Malak Malak Ranger Group is the Indigenous land management group for Malak Malak country on the Northern Territory's Daly River. Australia's northern rivers are one of the last remaining strongholds for the threatened Largetooth Sawfish and protecting them here may be the species' only hope of survival.

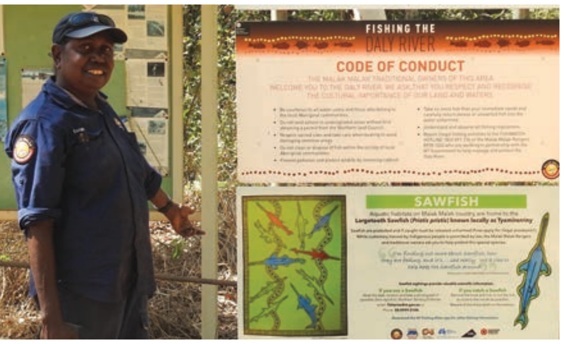
Hub researchers showed the rangers how to catch, handle and measure animals, and learned about the best places and times to find sawfish, and how they are valued and used. The knowledge helped in the tagging and tracking of juvenile sawfish, which provided valuable information about their movements.

The Malak Malak Rangers initiated an annual search for sawfish as a locally driven conservation measure. Juveniles sometimes become trapped in isolated floodplain waterholes linked to the Daly River, and may die if the waterholes dry up before the next wet season. Working together, the rangers and scientists have successfully relocated more than 60 Largetooth Sawfish. To help the community with this initiative, scientists and rangers developed a protocol for sawfish patrol and relocation. They collaborated to learn more about the connectivity of threatened Speartooth Shark populations.

Hub researchers and Malak Malak Rangers travelled to Roper River to work with Yugul Mangi Rangers from Ngukurr and their northern neighbours the Numbulwar Numburindi Amalahgayag Injung Rangers. They searched for sawfish, shared stories, and visited Ngukurr Art Centre to examine sawfish in local art. Sawfish-themed paintings were commissioned from two local Indigenous artists, Norman Wilfred and Theresa Lemon, to help make interesting, attractive, culturally inclusive and locally relevant communication materials. The process of engaging local artists was carefully managed to specify the potential future uses of the artworks, which generated significant interest in the local community.

Three videos prepared to raise awareness about sawfish conservation incorporated artwork and interviews from the three regions. Tyemirerriny is the Malak Malak name for the Largetooth Sawfish. The *Tyemirerriny* video features Malak Malak rangers talking about their interest in sawfish, and their wish to learn more about caring for sawfish as part of looking after the future of their country. *Save a Sawfish* features an animated sawfish decorated with artwork by Norman Wilfred that shows how sawfish should be released after being accidentally caught on a line or in a net. This video is narrated in English and Kriol, a language of the Roper Gulf region. The third video shows Malak Malak, Numbulwar Numburindi Amalahgayag Injung and Yugul Mangi rangers talking about sawfish territory.

Sawfish artwork was also used to illustrate public signs about sawfish that were erected at boat ramps and river crossings. Ngukurr and Numbulwar rangers requested the educational signage, which they felt would empower them to speak to people about doing the wrong thing regarding take of sawfish. This includes both any take by non-Indigenous fishers (which is illegal) and the practice of Indigenous people from other communities taking sawfish solely for their rostrum. This is something the rangers consider wasteful and therefore unacceptable. The educational materials were developed under the guidance of the North Australian Indigenous Land and Sea Management Alliance Ltd.



ABOVE: **Malak Malak ranger Theresa Lemon with a sign featuring her artwork, at Woolianna boat ramp on the Daly River.** Image: Malak Malak Rangers

The *Save a Sawfish* video shows how Largetooth Sawfish should be handled and released after accidental capture.

Recovery and assessment of threatened and migratory species

Southern Right Whale. Image: Andrew Halsall

West Alligator River.
Image: Michael Lawrence-Taylor

Shoring up euryhaline sharks in Australia's northern rivers

Northern Australia is a last remaining stronghold for globally threatened populations of euryhaline sawfishes and river sharks.

This Hub project provided information on the habitat, distribution, ecology and population dynamics of the Largetooth Sawfish and the Northern River Shark to assist in their conservation, management and recovery. The Largetooth Sawfish research relied on enduring partnerships established with Indigenous organisations, communities and ranger groups (see story on page 54). The Northern River Shark research found this shark to be more wide-ranging than previously thought, with new populations documented in several northern rivers.

Approach and findings

Northern River Sharks (*Glyphis garricki*) are found in brackish tidal rivers and estuaries of northern Australia and southern Papua New Guinea. They were listed as Endangered in 2001 under *Australia's Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999) and are subject to a national recovery plan. Distribution, population status and trend, and connectivity information is critical to the plan's implementation.

Hub researchers encountered the sharks in 2013 during field studies for the National Environmental Research Program. They began targeted surveys in 2015 under the National Environmental Science Program, bringing together a team from Charles Darwin University, CSIRO, the Malak Malak Ranger Group, Dambi Rangers, Nyikina Mangala Rangers, Northern Territory Department of Primary Industry and Resources, and Murdoch University.

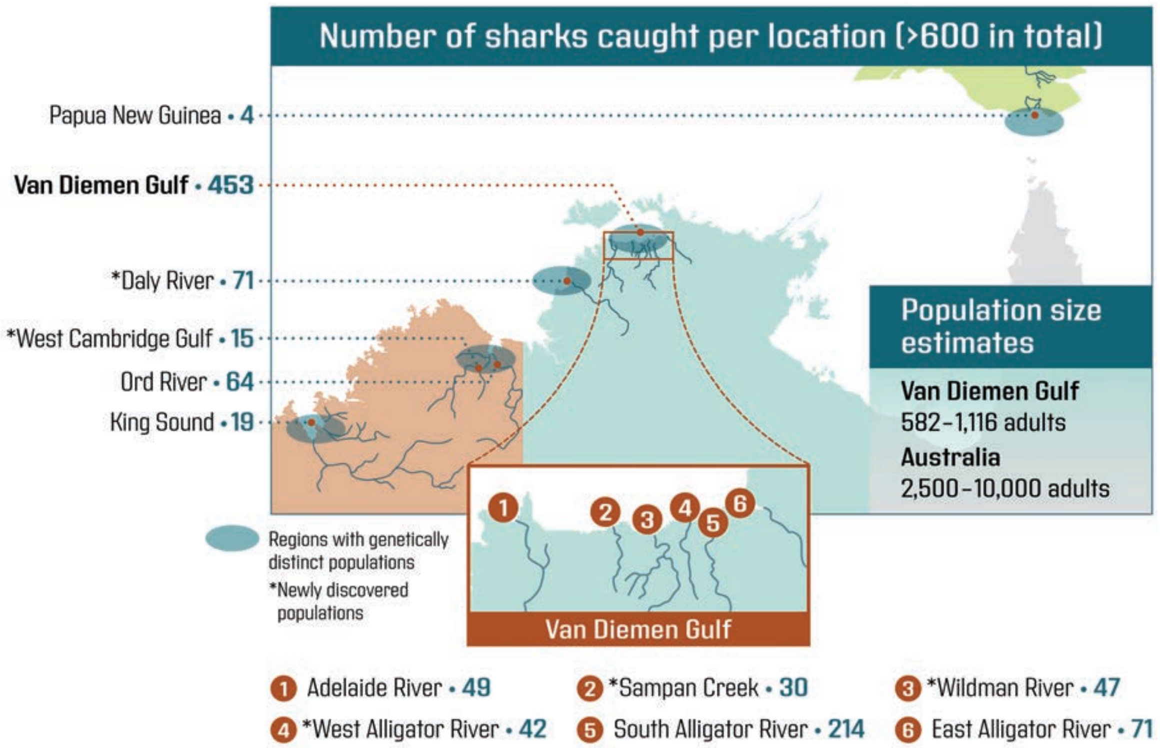
Nearly a decade of surveys discovered several new populations in northern rivers and identified nursery grounds in Kakadu National Park and World Heritage Area. More than 600 individual sharks were sampled in 11 rivers and estuaries across four different regions of Australia: from the Northern Territory's Van Diemen Gulf and Daly River, to Cambridge Gulf and King Sound in Western Australia's Kimberley region. Close-kin mark-recapture analyses enabled the first population size estimates and five distinct populations were identified: four in Australia and one in Papua New Guinea. Four of the rivers and estuaries that host the Northern River Shark run through Kakadu National Park and World Heritage Area to Van Diemen Gulf. Each of these rivers is a nursery area that provides essential protection for the Gulf population. Through this research, Kakadu has been highlighted as a site of global significance for the species.

Outcomes and next steps

This research dramatically increased understanding of Northern River Sharks, which a decade ago were known from only 32 records. It established effective approaches to monitoring and population assessment, providing knowledge and capability directly relevant to understanding population status and trends. Six additional rivers were added to the species' previously documented range, and genetic analyses identified distinct populations in different river systems. This enabled the first estimates of population size.

These findings are invaluable to the effective management and conservation of Northern River Sharks, and to environmental assessments conducted in the context of northern Australia's development. New evidence of population size and structure supports 'down-listing' of the Northern River Shark from Endangered to Vulnerable under the EPBC Act 1999, but highlights the need for localised management. The research also identified Kakadu National Park and World Heritage Area as a site of global significance for the Northern River Shark.

NORTHERN RIVER SHARK POPULATION LOCATIONS AND SIZE ESTIMATES IN NORTHERN AUSTRALIA AND PAPUA NEW GUINEA



FURTHER INFORMATION
peter.kyne@cdu.edu.au
Population size estimate of Glyphis garricki in the Northern Territory

Largetooth Sawfish.
Image: Peter Kyne

Compiling a file on Largetooth Sawfish life history

The Critically Endangered Largetooth Sawfish is extinct or severely depleted in much of its former range and some remaining populations are protected. Substantial new biological information is unlikely to become available.

Hub researchers reviewed all available life history information on size, age and growth, reproductive biology, and demography as a resource for population assessment and demographic modelling. This included a subset of data from the 1970s relevant to the maternal size-litter size relationship. All information was derived from northern Australia and the Lake Nicaragua-Río San Juan system (Central America) subpopulations.

The study found that Largetooth Sawfish grow to at least 705 cm in length, with birth length ranging from 72–90 cm. Females mature at 300 cm and males mature at 280–300 cm. Age at maturity is 8–10 years, longevity is 30–36 years and litter size is 1–20 (mean of 7.3 in Lake Nicaragua). Reproductive periodicity is suspected to be biennial in Lake Nicaragua and annual in Australia.

Future demographic models should aim to capture the variability and uncertainty in life history parameters for this species. A conservative approach is encouraged to any application for conservation and management.

FURTHER INFORMATION
peter.kyne@cdu.edu.au
Life history of Largetooth Sawfish

A tagged White Shark.
Image: CSIRO

Sizing up White Shark populations

White Sharks have been protected in Australia since the 1990s. An effective means of estimating population size and trend was needed to assess national recovery actions and local policies governing human-shark interactions.

This Hub project developed and applied White Shark population assessment tools and techniques to support national strategies for population monitoring. The approaches were developed under the National Environmental Research Program Marine Biodiversity Hub (the forerunner of the NESP). It provided the first direct estimate of population size for White Sharks in Australia.

Approach and findings

Building species population models has many challenges including gathering life history measurements and at least one count of a distinct age group, such as the number of juveniles or adults in the population. An understanding of movement patterns is also needed in order to distinguish overall trends from local fluctuations in numbers. All these parameters are difficult to measure for White Sharks. This project addressed these challenges with a unique application of electronic tagging and tracking, collection and archival of tissue samples, and a combined genetic and statistical technique called 'close-kin mark-recapture'.

Tagging data and genetic evidence suggests two populations of white sharks exist in Australia: an eastern population ranging from Tasmania to central Queensland and across to New Zealand, and a southern-western population ranging from western Victoria to north-western Western Australia. The eastern population was the first to be targeted for population assessment.

Long-term satellite tracking and acoustic tagging had been used to monitor shark movements, habitat use and survival, with a focus on juvenile aggregations at coastal nursery areas near Port Stephens, New South Wales, and Ninety Mile Beach in eastern Victoria. Aerial surveys and baited remote underwater stereo video had been trialled for counting juvenile white sharks, monitoring tagged individuals and estimating size and growth. The novel advances developed in this project involved the tagging and acoustic tracking of juveniles to derive their survival rates, and the use of close-kin mark-recapture to estimate adult abundance.

For the eastern Australasian white shark population, adult sharks were counted without the need to catch or even see them. Instead, their distinctive genetic marks were identified in the genes of their offspring. DNA sequencing of tissue samples collected from 214 juveniles identified the parents and related individuals (kin), and mitogenome sequencing identified the sex of the parents. More than 70 individuals were found to share a parent. 'Close-kin' analyses were then applied to provide life history measurements for the population model. The close-kin approach provides three important measures for the population model: the number of breeding adults, how frequently they breed, and rates of survival.

Using close-kin mark recapture, this project estimated the number of adults in Australia's 2017 eastern white shark population to be 750 (with a range of 470–1030). Because juvenile survival rates are known for the eastern population, a total population estimate is also possible, and this is 5460 (with a range of 2909–12,802). This direct estimate of total White Shark abundance and survival is calculated from data gathered across the geographic range and life-history of the population and sets a pathway to estimate total population trend.

The eastern adult population has been stable since the onset of white shark protection (at the end of the 1990s). This is consistent with the long time it would take for the effects of the various control programs and levels of fishing that existed pre-protection (which focused mostly on juveniles) to flow through to the adult population.

For the southern-western population, adult abundance and survival estimates were calculated from data on the number of sibling pairs detected in 175 high-quality DNA samples collected from sub-adult and young adult males across the southern-western population range, from Geraldton in WA to western Victoria.

The DNA analyses identified 41 closely related pairs in the southern-western white shark dataset: 27 half-sibling pairs that shared either a mother or father, and 14 full-sibling pairs that were each from the same litter and shared both parents. The southern-western adult population is estimated to number 1460 sharks (with an uncertainty range of 760–2250). Direct estimates of juvenile survival rates (a crucial piece of information obtained by tagging a relatively high number of juvenile sharks) are not available for the western population, so a whole-of-population estimate has not been compiled. As in the east, the southern-western adult population size is estimated to have been stable since the onset of white shark protection.

Outcomes and next steps

Providing reliable information on the size and trend of Australia's white shark populations has hitherto been an impossible task. This research demonstrated the effectiveness of linking juvenile survival rates derived from acoustic tagging with close-kin mark-recapture to estimate status and trends. The robust population estimates reduce uncertainty about conservation listings and provide a means of measuring the effectiveness of recovery actions under the *Environment Protection and Biodiversity Conservation Act 1999*, and state legislation.

New mapping of movement and habitat use supports ecological risk assessments, monitoring and management of marine parks, and collaboration between institutions and jurisdictions. Advances being made in this research – building coordinated national sampling regimes to measure key biological parameters using close-kin mark-recapture, and conducting electronic tagging and targeted surveys, and combining these in population models – will significantly improve our understanding of white shark populations in Australia.

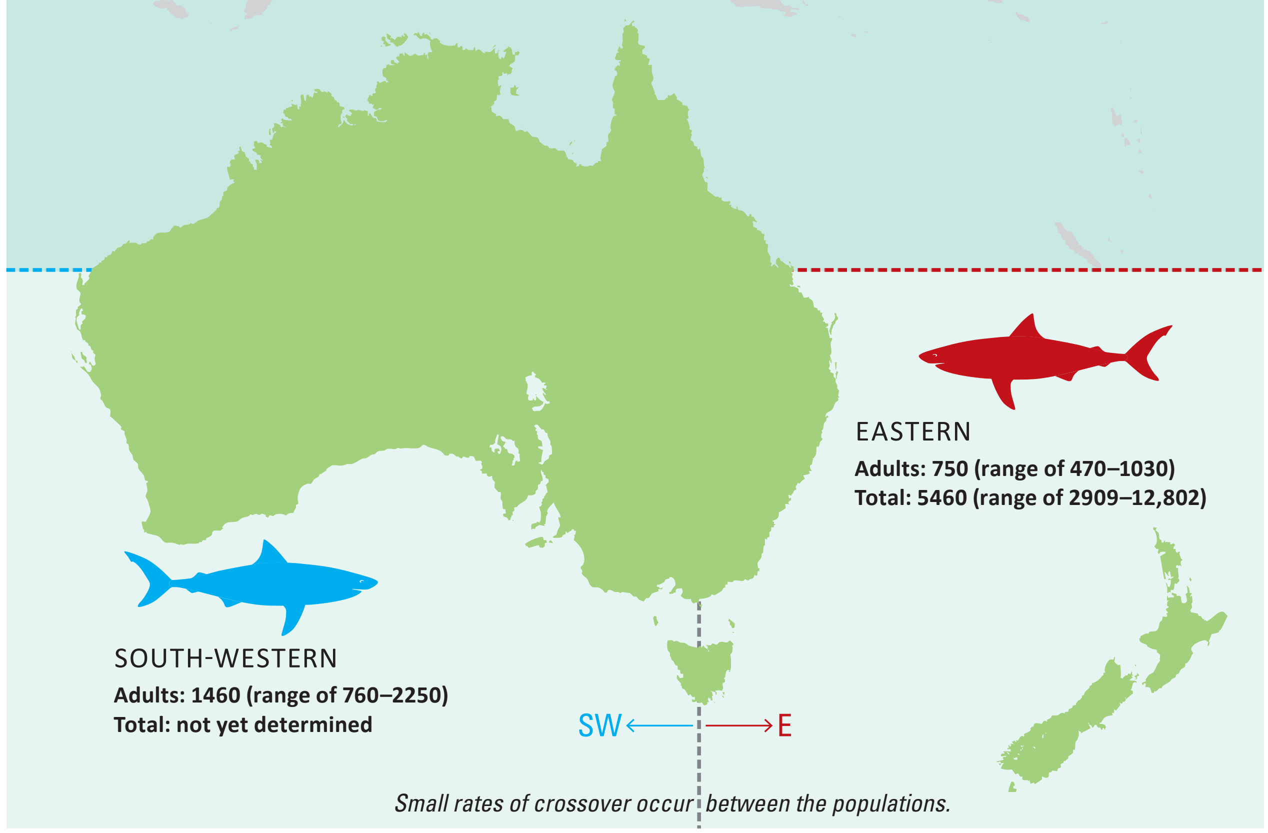
Estimating the trend in total population size requires continued sampling and close-kin analyses, using methods and institutional relationships developed in this project. This extensive and crucial collaborative network includes the New South Wales Department if Primary Industries, Western Australian Department of Primary Industries and Regional Development, South Australian Research and Development Institute, South Australian Department for Environment and Water and Flinders University.

It is possible, but unknown, that juvenile numbers have increased as a result of legislative protection enforced since the late 1990s. But sharks take 12–15 years to mature, so any consequent increase in the adult population would not occur until the next few years.

Based on current sampling rates the signal of any increase will take five years or more to detect with a reasonable degree of certainty, and more time will be needed for the southern-western population than for the eastern population. This is because current sampling in the south-west is limited to older animals as there are no identified nursery grounds where samples of juveniles can be reliably collected. Increased sampling rates and targeted sampling of juveniles may allow the signal to be detected sooner.

FURTHER INFORMATION
russ.bradford@csiro.au
A national assessment of White Sharks

ESTIMATED SIZE OF AUSTRALIA'S WHITE SHARK POPULATIONS



4

Shark tracker

Russ Bradford tags a juvenile White Shark at Ninety Mile Beach, Victoria. Image: Kent Stannard

The waters surrounding South Australia's Neptune Islands are a popular destination for White Sharks. After a short stopover they may head for western Victoria or the North West Shelf, or possibly out to sea.

White Shark tagging at the Neptunes helped scientists draw the boundary between Australia's two white shark populations. Now the tagging has mapped more remote White Shark habitat, and pathways that connect them. In research supported by the Hub, scientists combined the tracks of 40 white sharks tagged over 15 years (2003–2017) at The Neptunes and at Doubtful Islands near Bremer Bay, Western Australia. Many of these sharks were tagged by Russ Bradford of CSIRO, leader of the Hub projects on White Sharks and Grey Nurse Sharks.

Mr Bradford tagged his first White Shark at The Neptunes in 2003 alongside his colleague and mentor Barry Bruce. "It was an exciting time because marine science was taking the next big leap in technology with the wider use of electronic tags," he says. "We tagged a 3.8 m female nicknamed Columba. I remember having to stretch out across her back to reach her dorsal fin and being amazed at how girthy she was."

The pop-up satellite archival tags and satellite-linked radio tags that contributed to this study collected 3,663 days and 109,900 km of tracking data, for individual swims of up to 381 days. They provided the best picture yet of how white sharks use coastal and ocean habitat off southern and western Australia. Twenty-nine sharks covered more than 1000 km each while tagged, with females in particular venturing further offshore than previously recorded in Australia. The females also covered broader longitudinal ranges, dived deeper – sometimes beyond 1000 m – and tended to occupy slightly cooler waters. "We weren't surprised by the differences because we had seen sex-differentiated behaviour at The Neptunes, with females visiting almost exclusively during winter, and males visiting year-round," Mr Bradford says.

Two of the tagged adult females took epic offshore excursions, during which they spent time above major seafloor features. One followed the shelf slope edge westwards from the Neptune Islands to the Recherche Archipelago off Western Australia in winter–spring, headed 1700 km south to the Heemskerk Fracture Zone, then west parallel to the Southeast Indian Ridge for 1000 km. The other covered 12,240 km in five months, going eastwards from South Australia into the central Tasman Sea in summer, then south to sub-Antarctic waters off Macquarie Island in the south-western Pacific Ocean, before returning via the Ninene Trough south-east of Tasmania. This is the first record of a white shark visiting Macquarie Island, although their presence had been suspected from wounds observed on sea lions and fur seals.

Similar journeys have been recorded in New Zealand and the mid-Pacific, but the attraction of the fracture zones is unknown. It's possible that the sharks use the distinctive magnetic fields to navigate to foraging areas such as canyons and seamounts. Sharks of both sexes made autumn–winter visits to The Neptunes and to productive canyons in the eastern Great Australian Bight such as the Murray Canyons Group south of Kangaroo Island.

Many strands of research came together to make this study possible, from protocols developed by Mr Bradford and Mr Bruce for catching and handling white sharks, to advances in interpreting location data. Also essential is the network of researchers who collaborate to address components of the national recovery plan. "Given the time, expense and technical challenges involved in white shark research, it would be very difficult to gain traction without national collaboration," Mr Bradford says.

The study's findings add to the body of knowledge that supports effective conservation management policy, ecological risk assessments for fisheries, monitoring and management of state and national marine protected areas, and the identification of potential risks of human-shark interactions.

"We still have so much to learn about this (southern-western) population," Mr Bradford says. "Our abundance estimate for the adult population is 2,500, which is few and far between when you consider the vast territory these sharks occupy. To count the full population, we need to tag and genetically sample more juveniles. This will give us survival rates and family relationships required to build a population model, and ultimately the monitoring capacity to assess the efficacy of recovery actions. My present focus is on finding where pupping occurs. We have tagged mature females and juveniles to try to get them to lead us to those areas. Unfortunately, we have not pinpointed a specific region."

FURTHER INFORMATION
russ.bradford@csiro.au
A national assessment of the status of White Sharks

Grey Nurse Shark.
Image: David Harasti

Population estimate charts Grey Nurse Shark recovery

Grey Nurse Sharks are found across tropical and temperate regions of the North and South Atlantic, Indian and western Pacific oceans, to depths of at least 230 m.

Australia has distinct eastern and western populations, each inhabiting an approximate 2700 km stretch of coastal waters. The eastern population ranges from central Queensland to at least the New South Wales/Victoria border and the western population ranges from Western Australia's North West Shelf to at least Cocklebiddy in the Great Australian Bight. The eastern population is Critically Endangered and has undergone a severe reduction in size due to activities such as fishing and shark control programs.

Reliable estimates of population size and trend are needed by Australian and state government agencies to address uncertainty and evaluate species recovery for the eastern population. A robust estimate of population size and trend is the number one priority of the species' recovery plan developed by the Department of the Environment in 2014. Previous Grey Nurse Shark population estimates relied on photo identification, but this technique can have challenges relating to covering the full geographic range of the population, and the accuracy of matching the sharks' spot markings.

FURTHER INFORMATION
russ.bradford@csiro.au
Grey Nurse Shark population size and trend estimate report

A new estimate of adult population size and trend for the eastern population generated in this Hub project drew on widespread genetic sampling and forensic exploration of family trees. The new knowledge will enable the recovery of the species to be assessed, and provide guidance for ongoing monitoring and other actions to assist species recovery.

Approach and findings

This CSIRO-led project collated existing tissue samples and collected new samples from Grey Nurse Sharks at aggregation sites in Queensland and New South Wales (in partnership with the University of Queensland and the New South Wales Department of Primary Industries). The samples provided genetic information for close-kin mark-recapture analysis to provide the most rigorous population size and trend estimate to date for the east coast population.

Close-kin mark-recapture builds on techniques developed in associated Hub research on euryhaline elasmobranchs and White Sharks. It uses cutting-edge genetic analyses of tissue samples to identify sharks that are related by sharing one parent (half-siblings). The number of half-siblings in a population is directly related to the number of breeding adults. For example, a smaller adult population will have a larger proportion of related sharks, and vice versa. The same genetic samples can be used to identify animals that share one grandparent, and this in turn can be used to estimate the number of adults in the previous generation. Comparing this estimate with the present number of adults may show the generational change in population size, or population trend.

The east coast Grey Nurse Shark adult population was estimated to be between approximately 960 and 3,100 animals (depending on the selected maturity schedule). Importantly, the model used to derive this population estimate supports a growing population of approximately 3.4 to 4.5% a year.

Outcomes and next steps

The new population estimate reduced uncertainty surrounding the recovery of the Grey Nurse Shark and contributed to community support for the shark's continued conservation under the *Environment Protection and Biodiversity Conservation Act 1999* and the New South Wales Fisheries Management Act 1994. The Australian and New South Wales governments are using the results in policy development and conservation management.

The modest population increase offers some evidence that this species is on the road to recovery. Despite this finding, the final report for this project does not advocate the lifting of existing protective measures. Further work on the level of risk facing the recovering population is required before it would be appropriate to alter the range of existing protective measures. Future research should seek to better understand age estimates derived from examining growth rings in shark vertebrae, continued tissue sampling of live animals, surveys using baited remote underwater camera systems, and continued photo identification.

4

Exploring connections between hammerhead shark populations

Northern Australia has two species of large hammerhead shark. Great Hammerhead Sharks and Scalloped Hammerhead Sharks are susceptible to fisheries bycatch and overfishing driven by international trade in fins and meat.

The Scalloped Hammerhead Shark is listed as Conservation Dependent under Australia's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999), and both species are listed under the Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES). The CITES listing reduces the threat posed by global trade. To receive an export permit, Australian fisheries that harvest these species as bycatch must show that they are not substantially increasing the risk of the sharks' extinction. This is called a Non-Detriment Finding (NDF).

Australian and state government agencies need a better understanding of hammerhead stocks in Australian waters to meet their obligations under CITES and the EPBC Act 1999, and to manage hammerhead shark populations caught in fisheries. A key question is whether the population(s) in Australian waters interbreed with populations overseas. International assessment and management may be required if the stocks are shared. Collaborative research led by the Hub generated a new understanding of how hammerhead shark populations are structured and connected across northern Australia and neighbouring nations.

Approach and findings

The need for this research was identified with the Department of Agriculture, Water and the Environment and Threatened Species Scientific Committee (TSSC). A national team was assembled from science agencies, the fishing industry, governments and Traditional Owner groups to facilitate collaborative research based on a shared understanding of issues and knowledge gaps.

Hammerhead sharks were tagged and tracked by researchers from the Australian Institute of Marine Science, Western Australian Fisheries, Northern Territory Fisheries and James Cook University. Commercial fishers and charter operators provided advice on shark locations, and Indigenous rangers from the Girringun Aboriginal Corporation, Yuku Baja Muliku, and Yirrganydji Traditional Owners joined Queensland tagging expeditions (see story on page 51).

Fourteen hammerhead sharks, (six great and eight scalloped hammerheads; 10 males and four females) were satellite-tagged. The sharks stayed reasonably close to the coastal tagging sites, with the furthest venturing 121 km. This was a great hammerhead tagged off Bowen, Queensland, which moved north to Townsville and Palm Island. Three hammerheads tracked for six months in Exmouth Gulf, Western Australia, all stayed in the Exmouth area.

All the tagged animals were relatively small (about 2 m). Larger animals may move larger distances.

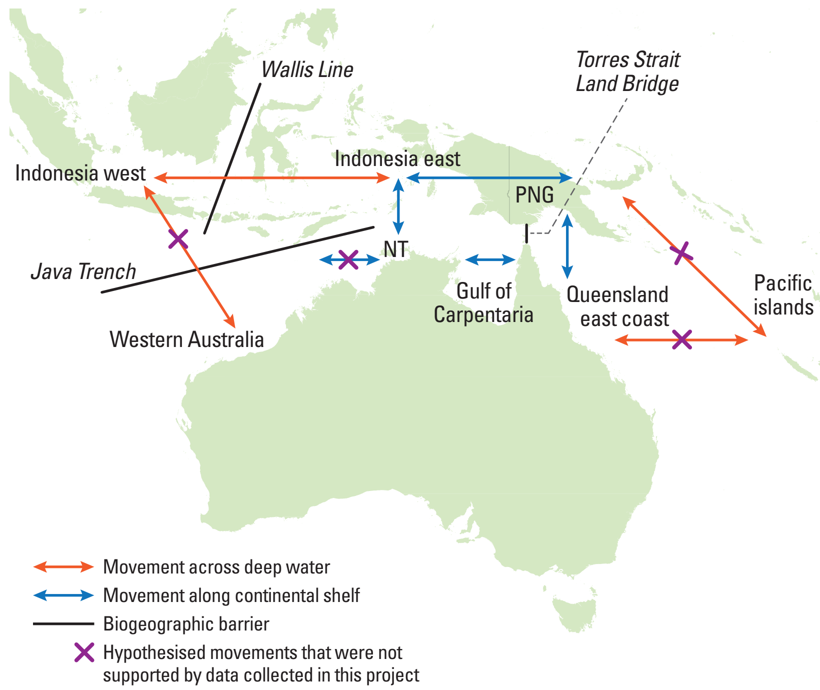
National collaboration with data holders opened up access to existing data, including commercial catch records. These were combined with the new project data – from tagging, genetics and shark parasite research – and Indigenous knowledge, to determine how Australian populations are structured, distributed and connected with stocks in other countries such as Indonesia and Papua New Guinea.

Genetic data indicate Australian hammerhead populations are connected to those in Indonesia and Papua New Guinea, but tracking and parasite data suggested limited movement between countries. The Western Australian Scalloped Hammerhead population is distinct from other parts of Australia, Indonesia and Papua New Guinea.

TOP: **Researchers seeking and tagging hammerhead sharks on the Great Barrier Reef.** Images: Alex Vail and Fernanda De Faria

BELOW: **Tagged hammerhead sharks remained reasonably close to tagging locations.** Image: James Cook University

CONNECTIONS BETWEEN SCALLOPED HAMMERHEAD SHARK POPULATIONS



Outcomes and next steps

This project provided data on hammerhead sharks movement and population structure that were critical to a stock assessment model developed for Australia's western, northern and eastern stocks by the National Scalloped Hammerhead Stock Assessment Team. The project findings and modelling were shared in briefings with departmental staff and the TSSC, to help form recommendations to the Minister for the NDF review. They also contribute to state-based management of sustainable harvests. The apparent isolation of the Western Australian Scalloped Hammerhead population is important information for fisheries stock assessments.

Further research is needed, particularly given the difficulty of reliably catching and sampling adult hammerhead sharks in Australian waters. The presence of juveniles and sub-adults in coastal areas suggests they give birth locally, but it is unclear where adult and pregnant individuals reside. This information is critical to fully understanding the residency of the Australian population.

Further sampling in regional neighbouring countries such as Indonesia and Papua New Guinea would help refine understanding of population connectivity. For example, satellite tagging of large females encountered outside Australia could reveal whether these individuals move to Australia, especially for the purposes of pupping. Prioritised collection of genetic samples from large hammerheads in the region would enable genetic studies to further explore stock structure.

Finally, additional research is needed to more fully understand the biology and ecology of Great Hammerhead and Winghead Sharks. Future research should use as many samples and methods as possible from as many locations as possible to refine our understanding of hammerhead populations within and beyond Australia to inform state and territory, Commonwealth and international cross-jurisdictional management.

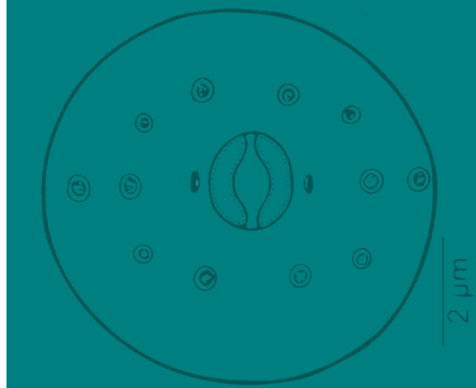
FURTHER INFORMATION
michelle.heupel@utas.edu.au
Examination of hammerhead shark connectivity

New parasite species attaches to biological tagging study

A Hub study of parasites retrieved from the spiral valves of 266 hammerhead sharks found two species of parasitic nematodes. *Piscicapillaria bursata* was subsequently described as a new species. *Parascarophis sphyrnae* represented a new geographical record of this parasite outside the Atlantic Ocean.

The Great Hammerhead Shark and Scalloped Hammerhead Shark samples used in the study came from the Northern Territory, Queensland, northern New South Wales and Lombok, Indonesia. Researchers characterised the parasite assemblages for use as biological tags to help identify connections between populations.

For both shark species, the parasite assemblages were significantly different between the Northern Territory, Queensland and New South Wales. Differences between the assemblages from the Australian and Indonesian samples pointed to a limited degree of connectivity between hammerhead shark populations in the two regions.



A sketch depicting the head of the parasite *Parascarophis sphyrnae*. Plate-like structures in the mouth are a distinctive feature.

First national action plan maps a future for sharks, rays and chimaeras

Colclough's Shark has only six or seven pups each litter and possibly breeds only once every two or three years. Image: Nigel Marsh

Australia is home to 328 species of sharks, rays, and chimeras: more than a quarter of all the 'shark' species on the planet. They have life history characteristics that render their populations susceptible to the impacts of human activities and climate variability.

As these pressures escalate, a national approach was needed to consolidate and present the latest knowledge of species' population status, threats, protection measures and management solutions. This knowledge underpins species listings under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999). It also supports the prioritisation of shark research, and national and state conservation and fishery management.

The Action Plan for Australian Sharks and Rays 2021 published by the Hub reviews the national status of each Australian species, showcases their rich diversity, and sets a benchmark for measuring future changes in their status.

Approach and findings

The national status of each species was assessed using the International Union for Conservation of Nature (IUCN) Red List Categories and Criteria, which are broader than those established under the EPBC Act 1999. This approach allowed the status of every species to be categorised by the Hub team.

The six categories defined under Australia's EPBC Act 1999 do not provide a place for species with lower levels of extinction risk. Additional Red List categories that are not provided under the Australian system include Near Threatened, Least Concern, and Data Deficient. Applying this full spectrum of categorisation is particularly important to demonstrate the high level of secure species. For example, 70% of Australian sharks were assessed as Least Concern and 10% were assessed as Near Threatened.

The species catagorisation process involved extensive consultation and review with people involved in shark research, policy development, conservation and fishery management. This ensured the format of the book aligned as closely as possible with the needs of research users. Information was gathered from a wide variety of published and unpublished sources, and expert knowledge.

The good news is that overall, sharks and their relatives are doing better in Australian waters than in many other areas of the world, with a relatively low level of threatened species. Some 80% of Australia's species did not meet the criteria for a threatened category. But there are some troubling exceptions. The book reveals that 12% of Australian sharks are threatened. While this is considerably lower than the global tally of 32%, it does raise concerns for the 39 Australian species assessed as at risk of extinction. There are positive signs that protection and management is working for some iconic species such as the White Shark and Grey Nurse Shark, although the Action Plan showed that these species remain threatened.

The Action Plan also identifies 46 'lifeboat' species, such as the Giant Guitarfish and the Spotted Eagle Ray. Australia provides a refuge for these species which are in trouble elsewhere in the world. For oceanic species that range beyond international borders, such as the Critically Endangered Oceanic Whitetip Shark, Australia will need to continue to engage globally and increase domestic management measures to allow populations to recover.

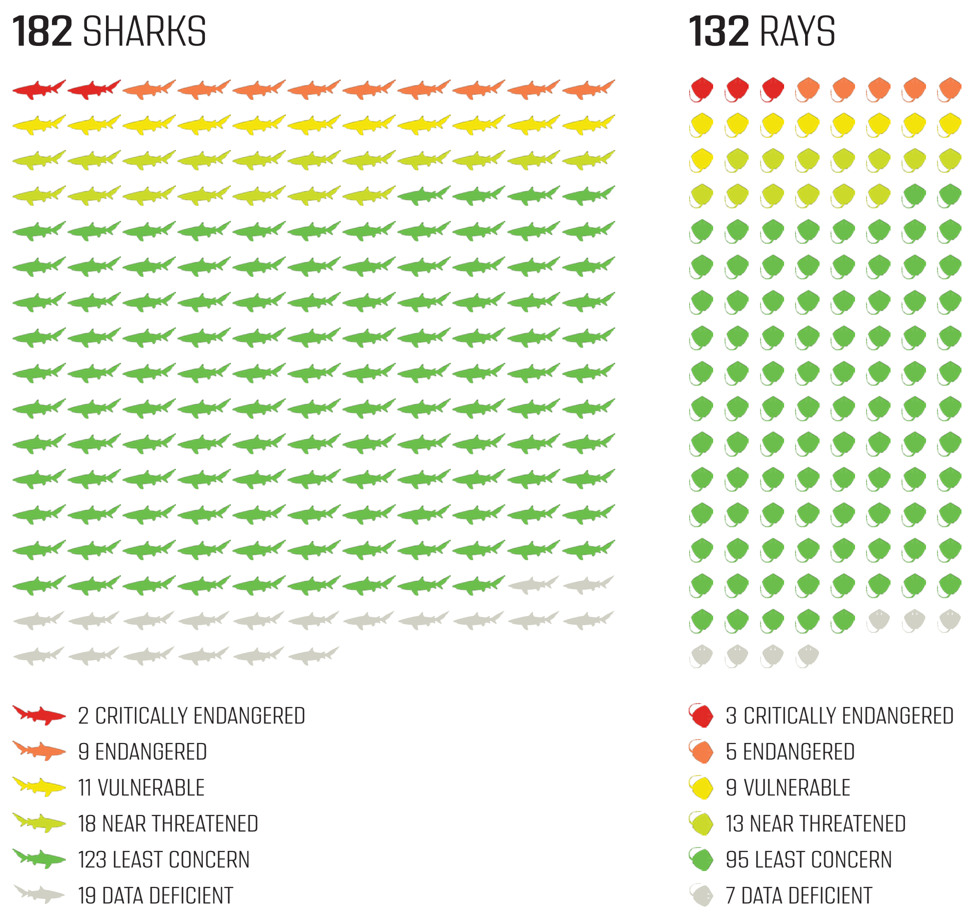
Outcomes and next steps

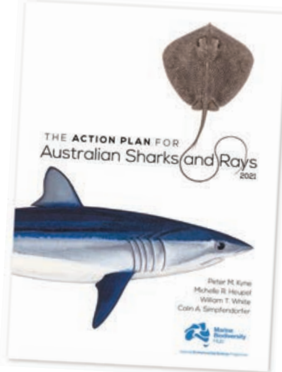
The Action Plan for Australian Sharks and Rays 2021 is the first attempt to provide managers of sharks and their habitats with a consolidated, national-scale overview that identifies priority at-risk species, species that may need future protection, and species of no immediate conservation concern. It also identifies knowledge gaps that may affect our ability to adequately understand population status and efficacy of management.

The Action Plan makes several recommendations regarding the need to list threatened species under the EPBC Act 1999. This includes identifying five species for immediate listing. It also shines a spotlight on a group of species for which research is urgently needed to understand their status.

FURTHER INFORMATION
peter.kyne@cdu.edu.au
The Action Plan for Australian Sharks and Rays 2021

EXTINCTION RISK ASSESSMENT FOR AUSTRALIAN SHARKS, RAYS AND CHIMAERAS*





*based on IUCN Red List Categories and Criteria

Fears held for camouflaged species

Peter Kyne of Charles Darwin University is the lead author of *The Action Plan for Sharks and Rays of Australia 2021*. He says that while we should celebrate the secure status of many species, we urgently need to increase research and management efforts for Australia's threatened sharks and rays.

As well as wrangling the latest national knowledge on sharks, Pete devotes time to global initiatives such as the International Union for Conservation of Nature. He also spends several months each year in the field: studying euryhaline elasmobranchs in Australia's northern rivers, and engaging in on-gound conservation with Indigenous communities. One of his concerns is that lesser known shark species are overlooked. "Many of our threatened sharks and rays are not commercially important so are largely 'out of sight and out of mind'," he says. "But they require protection at national and state/territory levels."

Two examples of lesser known species are Colclough's Shark and Coastal Stingaree. Colclough's Shark lives off Australia's east coast, from Byron Bay to central Queensland, snoozing under rocky reef ledges by day. At night they forage around reefs and seagrass beds, which puts them in the path of prawn trawlers. Their habitat is degraded by urban development, particularly in important places such as Moreton Bay. There are fewer than 80 formal records of Colclough's Shark, even though their habitat has been well surveyed and researched.

With 21 species parked around our seafloor, Australia has the world's greatest diversity of stingarees. The Coastal Stingaree lives only in the eastern Great Australian Bight and has only one or two pups every one or two years. Prawn trawling operates across about half of its known range, and their populations have declined in these areas. Surveys at 65 sites in the Spencer Gulf in 2013 found only one individual.

ABOVE: **Peter Kyne with *The Action Plan for Australian Sharks and Rays 2021.*** Image: Robin Leppitt.

Coastal Stingaree numbers appear to have halved in the past three generations (26 years). Image: David Muirhead

Monitoring the recovery of Southern Right Whales

The Southern Right Whale is listed as Endangered under the *Environmental Protection and Biodiversity Conservation Act 1999* and is subject to conservation listings in five Australian states due to severe population declines caused by historical whaling.

The *Conservation Management Plan for the Southern Right Whale 2011–2021* provides a framework for collaborative efforts between countries and other stakeholders to protect and rebuild populations, as required under Australia's membership of the International Whaling Commission. The plan must be periodically updated to reflect new knowledge and prioritise the research needed to monitor population recovery and predict the impacts of threats such as climate change.

Hub researchers advanced this capacity by conducting annual aerial surveys of the south-western Southern Right Whale population, and transforming the utility of the national photographic data catalogue.

Approach and findings

Annual aerial population surveys

Annual aerial surveys for the south-western sub-population (the majority of the Australian population) have been conducted between Cape Leeuwin, Western Australia, and Ceduna, South Australia, since 1993. The week-long surveys occur in August and involve 40 flying hours. The Hub funded the survey and associated data analyses from 2016 to 2020. The whale sightings and identifying photographs are held in the Australasian Right Whale Photo-Identification Catalogue (ARWPIC) hosted by the Australian Antarctic Division.

The whale count data from the 2020 survey showed a significant decrease in overall sightings that had not been observed for more 13 years. The subsequent population estimate for Australia's south-western sub-population was 2585 whales. This marked a significant decrease in estimated population size, which was 3164 in 2019.

An extremely low number of unaccompanied adults (68) had the greatest impact on the overall number of sightings in 2020, and was the lowest number sighted since 1993 (47). Previous surveys in 2007 and 2015 were noted as years of low whale counts that had been deemed anomalous years. The low numbers from the 2020 survey questions this assumption, and may suggest that the three-year female breeding cycle is becoming more unpredictable.

Australasian Right Whale Photo-Identification Catalogue

Until 2018, this catalogue served only as a data repository, rather than a system to support formal population analyses.
A second hub project assembled a team of national and international specialists to expand the capability and usability of the ARWPIC. Additional data streams associated with Southern Right Whale sightings across user groups in Australia were added to the catalogue and unified to be nationally comparable. These included land based surveys at Head of the Bight, South Australia, and Logan's Beach, Victoria, aerial survey data from Western Australia, and opportunistic data collected in Tasmania, Victoria and New South Wales. This process increased the coverage of the catalogue to nearly 7000 sightings of more than 2500 individuals spanning 1978 to 2019.

Bringing all these datasets online was a huge undertaking. Each whale had to be classified to identify its individual features and matched against all other whales in the catalogue to determine whether the whale had been re-sighted, or was a new encounter. This process was verified by experienced curators to ensure quality and accuracy. Improved data-entry processes also were developed.

The consolidated sightings data highlighted aggregation sites along the south-western coastline including Albany east to Doubtful Island Bay, Israelite Bay to Point Culver, Twilight Cove and Head of the Bight, plus emerging aggregation areas in eastern South Australia such as Encounter Bay. In the south-east, potentially important habitat included south-eastern Tasmania and south-western Victoria. Few individuals (2.5%) were recorded in both the south-west and south-east.

Outcomes and next steps

This Hub research provided the Australian Government with evidence to understand and report on the status and recovery of Southern Right Whales in Australian waters, and supports specific actions in the Conservation Management Plan.

The comprehensive national ARWPIC dataset is a vital step towards developing a national population estimation model as the basis for monitoring Australia's Southern Right Whale population. Automatic reporting now facilitated by the database makes it relatively easy to query details such as when individual whales are sighted at particular breeding sites or stopover points.

An additional benefit has been the bringing together of the Southern Right Whale community in a positive and collaborative effort, with the result that sighting information is now more widely collected, shared and used. The catalogue is also accessible to members of the public, who can match their own photographs of whales to those in the catalogue.

Identifying environmental drivers that might be associated with both the potential shift in population growth rate and cyclical anomalous years will be important to understanding the overall recovery of Southern Right Whales in Australian waters and should be a focus of future research.

Further research recommended to support the Conservation Management Plan includes:

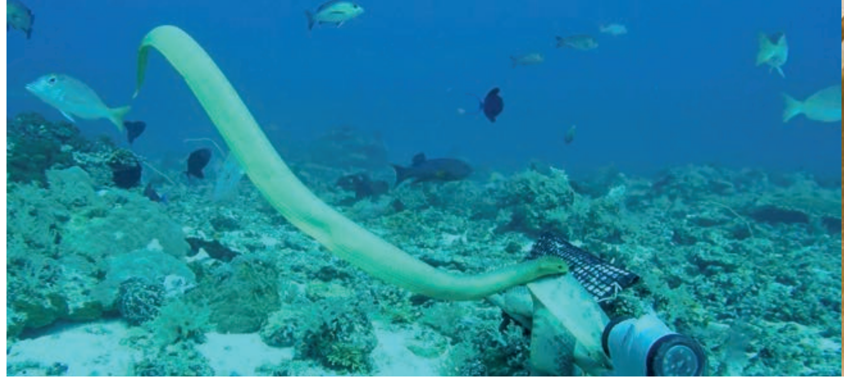
- continuing the annual survey of the south-western sub-population;
- dedicated surveys of the south-eastern sub-population;
- development of broadly accessible population modelling approaches;
- joint discussion of research prioritisation involving conservation managers, data holders, population modellers and funding agencies; and
- collection of genetic material to examine the level of interbreeding between the east and west regions.

FURTHER INFORMATION

joshua.smith@murdoch.edu.au
Monitoring 'western' Right Whales off southern Australia

karen.evans@csiro.au
Estimation of population abundance and mixing of Southern Right Whales

Groups of Southern Right Whales pictured socialising near dolphins in Dolphin Cove, WA, during the annual aerial population survey. Image: Joshua Smith



Slippery slopes for sea snakes

Many regions of Australia once were considered global hotspots for sea snakes, but reported population declines have raised concerns about their status.

In addition, species previously thought locally extinct in remote locations subsequently have been sighted. A better understanding of sea snake habitat, distribution, status and threats is needed to guide management and recovery plans for these species in Australian waters.

This Hub project compiled existing information about sea snake occurrence, assemblages and bycatch rates across Australia, and collected additional data in the North and North-west Marine Regions where information gaps persisted. The information was used to define distribution patterns, identify areas of high diversity and endemism, and assess the vulnerability of different species to being caught as bycatch in trawl fisheries. A particular focus was on three endemic species: the Short-nosed Sea Snake and Leaf-scaled Sea Snake, which are Critically Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999), and the Dusky Sea Snake which is a listed Marine Species.

Approach and findings

Occurrence records for sea snakes in Australian waters were compiled from *The Atlas of Living Australia*, Reef Life Survey, surveys by Hub partners and the University of Adelaide, and WA Fisheries observer data. A total of 8359 records representing 27 species were used to model general sea snake distribution for Australian waters based on habitat suitability. Species-specific distribution, diversity and endemism was then mapped for northern Australia.

South-western Gulf of Carpentaria had the highest sea snake diversity, with 17 species recorded, according to data primarily collected through trawl bycatch. The North-west Shelf region (Scott Reef and Ashmore Marine Park) had the highest level of species endemism, with all five of the endemic species known to have their global range in this region. The Anindilyakwa Indigenous Protected Area (IPA) around Groote Eylandt in western Gulf of Carpentaria had a significant diversity of sea snakes adjacent to highly productive trawl fishing grounds. Surveys conducted with Anindilyakwa Land and Sea Rangers identified species incidentally captured in large numbers by the adjacent trawl fishery.

To assess sea snake species exposure to trawl fishing across northern Australia, maps of predicted habitats were overlaid with annual fishing effort. A fishing exposure index was estimated to identify where habitats suitable for sea snakes were exposed to fishing. Hub researchers also worked with WA Fisheries to conduct trawl surveys in fishing grounds at Shark Bay, Exmouth Gulf, the Pilbara region between Onslow and Broome, and along the Kimberley coastline. The results were used to assess the assemblage of snakes encountered by commercial trawls, and the survival of snakes interacting with trawl gear.

The assessment of fishing exposure highlighted regions in the western Gulf of Carpentaria, and areas along the Pilbara coastline, where there was significant overlap between trawl fishing effort and highly suitable habitats for sea snakes. In the Gulf of Carpentaria, species with highly suitable predicted habitats and high exposure to fishing efforts are also known to frequently occur as bycatch of the Northern Prawn Fishery. These species include the Olive Sea Snake, Elegant Sea Snake, Stokes's Sea Snake and Horned Sea Snake

Preliminary species-specific interaction rates were assessed in four coastal areas of Western Australia; Shark Bay, Exmouth Gulf, Pilbara and the Kimberley. Catch composition across all four regions highlighted that sea snakes are encountered in relatively low numbers, with the highest encounter rates in Shark Bay. The two Critically Endangered species (Short Nosed and Leaf-scaled Sea Snakes) were encountered in Shark Bay and Exmouth Gulf respectively. Species on the west coast with restricted ranges that have highly suitable predicted habitats in known fishing grounds and are likely to have higher exposure to coastal trawl fishing include Brown-lined Sea Snake, Leaf-scaled Sea Snake and Shark Bay Sea Snake. A more comprehensive understanding of species-specific, pre and post-release survival rates is required to understand the impacts of continued high rates of trawl interactions for these species. In general, commonly encountered species such Olive Sea Snakes had high pre-release survival rates regardless of trawl duration, while larger species such as Elegant Sea Snake and Greater Sea Snake were likely to be encountered dead in trawl nets after trawls longer than 90 minutes.

Outcomes and next steps

The new understanding of sea snakes provided by this project is relevant to updating the status of key species identified as vulnerable or of conservation priority under the EPBC Act 1999. The Short-nosed Sea Snakes and Leaf-scaled Sea Snakes should remain a conservation priority due to uncertainty about why they disappeared from Ashmore and Hibernia Reefs, and the strong overlap of their newly described coastal populations with trawl fisheries. The Dusty Sea Snake should be considered for elevated conservation status due to the significant reduction of geographic range, unexplained local extinctions at Ashmore Reef, and mounting evidence of high rates of hybridisation in surviving populations.

Understanding how sea snakes use shallow habitats such as IPAs and other marine protected areas that restrict trawl fishing can help assess the impacts of the large bycatch rates on Gulf of Carpentaria populations. Research in this region highlights the importance of strong protections and limitations on fishing efforts in IPAs that allow vulnerable species such as sea snakes to recover from high interactions in adjacent trawl fishing grounds.

Future work can use the national baseline assemblage datasets and assess residency and movement patterns of sea snakes between those found in protected waters (such as Australian Marine Parks and IPAs) and those that interact with coastal fisheries (such as the Northern Prawn Fishery, Exmouth Gulf Trawl Fishery and Shark Bay Trawl Fishery). This research could involve a coordinated mark-recapture program, or tracking studies.

FURTHER INFORMATION
v.udyawer@aims.gov.au
Distribution, fisheries interactions and threats to Australia's sea snakes

TOP LEFT: **A Reef Shallows Sea Snake caught during spotlight surveys at Heywood Shoal. This species is often found at coral reefs and has uniquely small and irregular scales on its head.** Image: Vinay Udyawer

TOP RIGHT: **Olive Sea Snakes investigate a baited camera on the North West Shelf.** Image: Australian Institute of Marine Science.

LEFT: **The Short-nosed Sea Snake was classified as Critically Endangered based on population declines at Ashmore Reef. New populations were subsequently discovered in Exmouth Gulf, WA, and the species is encountered frequently in the Gulf trawl fishery.** Image: Vinay Udyawer

TOP: **A Turtle-headed Sea Snake caught during research trawls in fishing grounds of the Pilbara coast, WA. This unique species feeds on Damsel fish eggs. They have a variable yet striking colouration and a uniquely large scale on the upper lip that helps them forage for fish eggs and makes them resemble a turtle's head.** Image: Vinay Udyawer.

BELOW: **Sea snakes project leader, Vinay Udyawer of the Australian Institute of Marine Science, with Anindilyakwa Sea Rangers during marine surveys at Jagged Head and Umbakumba Bay.** Images: Australian Institute of Marine Science.

Sea snakes abound in Anindilyakwa IPA

Protected coastal areas such as the The Anindilyakwa IPA around Groote Eylandt in the Gulf of Carpentaria can provide refugia to populations of sea snakes that interact with trawl fisheries.

Hub researchers collaborated with Anindilyakwa Land and Sea Rangers to conduct opportunistic boat-based surveys, and record sea snakes encountered during the rangers' beach activities. Sea Ranger knowledge helped to target data collection, and the rangers learned to collect scientific data about sea snakes and other culturally important species.

The assemblage of sea snakes in the IPA was similar to those commonly encountered in adjacent fishing grounds, and included Elegant Sea Snake, Stokes's Sea Snake and Olive Sea Snake: species incidentally captured in large numbers in surrounding fishing grounds.

Sea Country in the Anindilyakwa IPA had the highest sea snake diversity and endemism identified in this project. High diversity was also identified in the Gulf's Thuwathu/Bujimulla and Dhimurru IPAs. The Yawuru IPA in Roebuck Bay, WA, had high levels of sea snake endemism.

An Australian Humpback Dolphin in tropical inshore waters. Image: Simon Allen

Tropical inshore dolphins: surfing under the radar

Tropical inshore dolphin species have been nominated several times for listing as Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999).

These nominations – for the Australian Humpback Dolphin and Snubfin Dolphin – were unsuccessful, largely due to a lack of information. Knowledge of tropical inshore dolphins in Australian waters was last reviewed in 2012. Since then, new data have been collected under the *Coordinated National Research Framework to Inform the Conservation and Management of Australia's Tropical Inshore Dolphins,* developed by the Department of the Environment.

This Hub project synthesised the results of numerous research and monitoring efforts completed since 2013 to improve understanding of threats and priorities relating to tropical inshore dolphins and provide evidence to support future assessments of their conservation status.

Approach and findings

Knowledge was reviewed for the Australian Humpback Dolphin, Australian Snubfin Dolphin, Indo-Pacific Bottlenose Dolphin and Spinner Dolphin. The geographic focus was on areas of northern Australia where these species co-occur: from Moreton Bay in Queensland and around the northern Australian coastline to Western Australia's Shark Bay.

FURTHER INFORMATION
simon.allen@uwa.edu.au
Conservation status of tropical inshore dolphins

New distribution, abundance and trends, habitat use and social and population structure data were available for the Humpback, Snubfin and Bottlenose species, but applied primarily to discrete study areas or, at best, some regions. The Spinner Dolphin group remains unstudied.

The life history characteristics of some tropical inshore dolphins remain largely unknown, but generally they are long-lived (multiple decades) and late to reach sexual maturity (a decade), with low reproductive rates (single offspring, several years apart). These life history characteristics make them particularly vulnerable to threatening processes and unnatural causes of mortality.

Although Australia's tropical inshore waters include areas relatively free from human activities, threats to dolphins in the region align with those ranked as the greatest to marine ecosystems globally. The main three threats are: habitat loss, degradation and contamination through coastal development; bycatch in fishing gear and shark nets set for bather protection; and climate change. The latter includes gradual ocean warming and acidification, as well as extreme weather events.

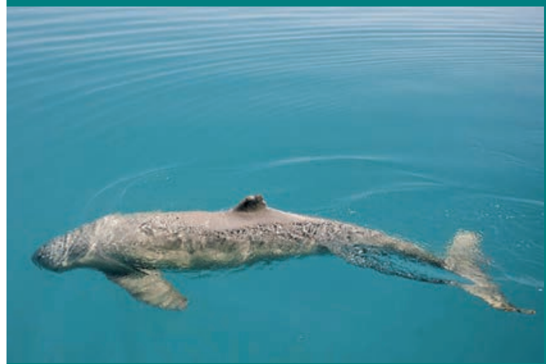
Several research and monitoring efforts have produced abundance and density estimates for discrete tropical inshore dolphin populations across northern Australia. One study integrated multiple data sources to estimate the extent of occurrence and area of occupancy of Snubfin Dolphins in the Kimberley region. The findings equated with a Vulnerable classification under International Union for Conservation of Nature criteria at a regional scale. A Hub project used distribution models to estimate areas of medium and high quality suitable habitat for Snubfin Dolphins and Humpback Dolphins. Combining these approaches across the northern Australian ranges of tropical inshore dolphins is likely to prove informative.

At a national scale, priority objectives identified in the Department's coordinated research framework remain unfulfilled. Broader data sharing and a nationwide assessment of abundance, trends or genetic population structure are yet to occur. At some sites where rigorous sampling has taken place, low abundance or movements over scales larger than the study areas have precluded mark-recapture modelling of abundance, movements and trends.

Outcomes and next steps

This project reviewed more than 150 reports and research papers to provide a consolidated knowledge update for four species of tropical inshore dolphins in Australian waters. It crystalised the evidence base available to support the evaluation of nominations to list these species under the EPBC Act 1999 by Australia's Threatened Species Scientific Committee.

In terms of assessing conservation status, a key challenge that remains is to estimate the number of animals in areas not yet surveyed. This would contribute national population sizes relevant to the consideration of conservation listings, in the face of uncertainty. Modelling of the likely number of mature individuals in the national 'population' of each species should be considered. This would be based on existing knowledge of sub-population sizes, distribution modelling of suitable habitat, and assumptions about numbers in unsurveyed areas. Multiple data sources could be integrated to estimate areas of occupancy.



ABOVE, TOP TO BOTTOM:

Humpback Dolphins pass the industrialised coastline of Port Hedland, WA.

A suspected dwarf Spinner Dolphin.

Australian Snubfin Dolphin.

Indo-Pacific Bottlenose Dolphin.

Images: Simon Allen

Australian Humpback Dolphin

Estimating the number of adults in the (national) population of Humpback Dolphins and Snubfin Dolphins is a high priority under the national research framework for tropical inshore dolphins. Nevertheless, no national population estimate is available for Humpback Dolphins, or indeed any tropical inshore dolphin species. There are estimates for discrete populations/study areas, at which Humpback Dolphins occur in generally low numbers (typically <100 individuals) and low densities (0.07–0.17 individuals per km²). An exceptional upper population estimate was reported from Port Essington in the Northern Territory (207, at a density of 0.64), although estimates fluctuated widely over time. The highest reported density was around the North West Cape in Western Australia (129 individuals in a 130 km² study area). Few studies have been long-term or resolute enough to detect trends in abundance, although declines in abundance have been reported in Keppel Bay and the Curtis Coast regions, Queensland, and Darwin Harbour, Northern Territory.

Spinner Dolphin

No national or local population estimates are available for any Spinner Dolphin subspecies in Australian waters. No trend data exist, nor are there published data on habitat use, social/population structure, life history characteristics or diet. Each of these traits is likely to depend on the ecotype/subspecies under consideration as they appear adapted to very different niches. Small forms of the species occur in Western Australia, the Northern Territory and at the southern end of the Great Barrier Reef.

Australian Snubfin Dolphin

No national population estimates are available for Snubfin Dolphins. They occur in relatively small populations (typically less than 100 individuals) in low densities (0.02-0.42 individuals per km²). Exceptional upper population estimates have been reported from Port Essington in the Northern Territory (222 individuals at a density of 0.68 individuals per km²), and the highest density thus far reported was in Roebuck Bay, Western Australia (133 and density 1.33). No broad population trend data are available.

Indo-Pacific Bottlenose Dolphin

No national population estimates are available for Bottlenose Dolphins, although several research and monitoring programs across northern Australia have produced abundance or relative abundance estimates. While some dedicated research efforts on Bottlenose Dolphins have yielded few sightings in particular habitats, others reveal sizeable populations of several hundreds to thousands of individuals (Moreton Bay, Queensland, and North West Cape and Shark Bay, Western Australia). Measures of Bottlenose Dolphin density are extremely variable. High densities (2.4–2.8 dolphins per km²) have been reported around the North West Cape, where there is also a high density of Humpback Dolphins. No reliable national trend data are available, although one study documented an immediate and long-term (seven-year) negative impact on survival and reproduction rates in western Shark Bay, Western Australia, following the 2011 marine heatwave that significantly reduced the cover of seagrass beds.

Helping handfish and their habitat

Spotted Handfish are found only in southern Tasmania's Derwent estuary, where fewer than 3000 individuals are thought to remain in fragmented populations. Red Handfish are known from only two small patches of reef in south-eastern Tasmania.

With a total population of about 100 adults, the Red Handfish is possibly the rarest marine fish in the world. Both species are listed as Critically Endangered under Australia's *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act 1999) and the International Union for Conservation of Nature's red List of Threatened Species. A national recovery plan sets out research and management actions to address the decline and support the recovery of these species in Australian waters.

This Hub project vastly improved knowledge of the life history of Spotted Handfish and Red Handfish, and the distinct problems they face in highly disturbed urban estuaries. Activities included GPS surveys; population dynamics monitoring and genetic studies; knowledge synthesis; creating artificial spawning habitats; deploying eco-friendly moorings; captive rearing; and replenishment of wild populations.

A hallmark of the work was close collaboration with government, industry, aquarists and the community through the National Handfish Recovery Team and the Handfish Conservation Project. Seahorse World and SEA LIFE Melbourne Aquarium helped to develop husbandry techniques and the Institute for Marine and Antarctic Studies (IMAS), University of Tasmania and CSIRO invested in aquarium facilities. SEA LIFE Melbourne Aquarium engaged in handfish sex-determination research to support captive breeding programs.

BELOW: **Spotted Handfish inhabit open sandy areas and lay their eggs on stalked ascidians.** Image: Antonia Cooper

INSET: **Ceramic artificial spawning habitat provides a substitute in areas where stalked ascidians have been lost.** Image: Laura Smith

Approach and findings

All known Spotted Handfish populations were located and individuals were photographed in annual GPS-based surveys. Adult individuals were tracked through time from their unique spot patterns. All population data collected since 1978 were standardised, providing the basis to analyse

Red Handfish are predominantly reef species. Their limited capacity for dispersal and proximity to coastal development makes them highly vulnerable to change. Image: Antonia Cooper

population dynamics in association with seasonality, ecological change and efforts to support breeding with artificial spawning habitats (ASH). This demonstrated an initial decline in Spotted Handfish which has since stabilised. This improvement is likely to be linked to the deployment of ASH.

Genomic studies of fin tags collected in 2006–2008 profiled gene flow between sites, identifying three to four distinct Spotted Handfish groups even at the very small scale of in the Derwent estuary. Populations at South Arm, Tranmere and Ralphs Bay, at Bellerive and Howrah, and at Battery Point and Sandy Bay were genetically distinct. Each isolated group is therefore highly vulnerable to being lost to a chance event and therefore requires individual management.

Spotted Handfish mostly inhabit soft sediments in 5–18 m depths that are populated by stalked ascidians which provide a substrate for eggs. They also inhabit pits created by skates and rays. These microhabitats can be destroyed by boat moorings and the removal of skates and rays. An underlying problem is the presence of the introduced northern Pacific Seastar which eats stalked ascidians. In the absence of stalked ascidians, Spotted Handfish lay eggs on artificial spawning habitat (ASH). Hub researchers worked with a Hobart artist to develop ceramic ASH as an alternative to the earlier use of plastic. Since 1998 close, some 14,000 ASH have been 'planted' by divers in areas where stalked ascidians have been lost. Handfish use ceramic in preference to plastic ASH.

Mooring fields tend to overlap with Spotted Handfish habitat. The chains typical of normal moorings scrape across the seafloor, removing handfish habitat. A new, environmentally friendly mooring design which costs the same as normal moorings was developed and tested. Engineering modelling showed the moorings reduced the shock loading on vessels by 39–58% during extreme weather conditions. By avoiding disturbance to the seafloor, they also allowed the recovery of Spotted Handfish habitat.

Spotted Handfish may live up to of 10 years, but most do not live past five years. They breed at two, however, leaving a very short window for reproduction. They also are direct recruiters: that is, their young do not undergo a planktonic stage. This is okay if the population lives in a good habitat – given a few good years the population can boom – but if the habitat is damaged, they cannot disperse to a new area, or recolonise in recovered habitat. This possibly underlies their steep population declines. On the other hand, stalked ascidians do have a planktonic stage. Young stalked ascidians can recruit to degraded areas. For example, if the Northern Pacific Seastar vacates a local area, the stalked ascidian habitat is much more robust to recovery than the handfish. This understanding is fundamental to the management response of restocking habitat with captive reared populations.

'Headstarting' Red Handfish

Little is known about the ecology and biology of Red Handfish, but they appear to favour sheltered, shallow rocky reefs, usually in depths of less than 10 m.

The females lay small egg masses in Spring at the base of seaweeds or seagrass and stand guard until the fully metamorphosed juveniles hatch at 4–6 mm in length. The lack of a planktonic stage limits the capacity for populations to mix, or colonise new areas. This life history, combined with their reliance on shallow coastal habitats near urban and industrial areas, makes them highly vulnerable to change.

Ongoing threats to degraded seaweed and seagrass habitat include pollution, excessive nutrients, warming seas, and native sea urchin booms. Large aggregations of urchins overgraze rocky reefs, creating 'barrens' that leave nowhere for the handfish to hide or breed.

In 2020, Red Handfish eggs were collected, hatched in captivity, raised and reintroduced to the wild at a site where urchins had been removed to allow habitat to grow back. The handfish were restocked, and initial surveys confirmed their survival.

This project also provided a risk assessment for Red Handfish and recommended management actions. Habitat must be monitored and an appropriate amount of urchins removed annually (low-density urchins maintain a mixed flora of seaweeds). Excess urchins are removed by University of Tasmania divers and commercial fishers: an activity that encourages positive engagement with stakeholder groups. Spatial management of these areas is also needed to help restore ecosystem balance.

4

Recovering/increasing the size of local Spotted Handfish populations would require captive breeding and restocking. As part of this project, holding facilities were developed at CSIRO and breeding events occurred in captivity from a gravid female collected in the wild. Breeding events also occurred in the Seahorse World and SEA LIFE Melbourne Aquarium 'insurance' populations. Cumulative knowledge gained over the course of the project is slowly determining the right environment in which handfish will breed on cue. If captive breeding can be established as routine, restocking could occur in areas where populations are locally extinct.

Outcomes and next steps

This project established new knowledge and methods for estimating, monitoring and conserving handfish populations, and helped to foster ongoing community support and collaboration. It had a direct impact on species recovery by increasing handfish numbers and providing evidence to support management measures under Tasmania's Derwent Estuary Program and nationally under the EPBC Act 1999, including implementation of the national recovery plan.

Sixty Spotted Handfish were raised in captivity and returned to the wild. Spotted Handfish are laying eggs on ceramic ASH. An eDNA marker developed by Hub PhD student Tyson Bessell is being used in research to detect the presence of Red Handfish in water samples.

Information on handfish life history strategies, age and growth, movements and threats were used in the 2019 IUCN Red List assessment and listing of handfish species, and the subsequent listing of Red Handfish in the Australian Government's top 100 priority species for the 2021 *Threatened Species Strategy*.

Information sharing between scientists, industry, and government planning authorities about the location of Spotted Handfish populations, and collaboration to manage spawning habitat, have been excellent project outcomes and should continue. This shared knowledge has raised awareness, including the need to consider their location in relation to development applications.

Research advice was incorporated in Tasmanian guidelines for estuarine and marine development proposals, and handfish location information was used by regulatory authorities to work with a development proponent planning a water pipeline between Hobart's western and eastern shore. The New South Wales government is using the project findings to help develop the first Australian standard for environmentally friendly moorings.

Captive animals of Red Handfish are maintained at Seahorse World, SEA LIFE Melbourne Aquarium and the IMAS Taroona aquaculture facility. Population bolstering and habitat restoration activities have improved Red Handfish sites temporarily, but management actions now needed to continue this work include habitat monitoring, management and mitigation of impacts, and the implementation of a captive-breeding program. Additionally, conservation actions need to consider the intentional capture and release of animals to establish the population in a new location as a viable long-term option.

Management actions recommended to maintain Spotted Handfish populations recognise that individual areas and populations need to be prioritised for conservation of spawning habitat. Ongoing monitoring should be undertaken of handfish populations and stalked ascidian habitat. ASH should be planted in areas where habitat is degraded. Another management challenge is to encourage yacht owners to swap from chain moorings to environmentally friendly alternatives.

TOP: **A Spotted Handfish lays eggs in captivity at CSIRO. Insurance populations of Spotted Handfish and Red Handfish were established at aquaria facilities.** Image: Carlie Devine, CSIRO

BELOW: **Divers from the Institute for Marine and Antarctic Studies and CSIRO return captive reared Red Handfish to a fragile patch of reef.** Image: Antony Cave, University of Tasmania

FURTHER INFORMATION
jemina.stuart-smith@utas.edu.au
Conservation of handfish and their habitats

5

Intervening to restore coastal habitat

Giant kelp. Image: Cayne Layton


Community blueprints for rebuilding shellfish reefs

Australia's native Flat Oyster reefs and Sydney Rock Oyster reefs are vital to the health and productivity of Australia's bays and estuaries, but only a fraction of these reefs survive.

Poor water quality and sedimentation as a result of catchment clearance, urbanisation and industrial pollution have exacerbated the loss of shellfish reefs. Reparation efforts have begun in some locations, with the promise of significant benefits. Further projects, however, hinge on increasing awareness and joint investment among governments, businesses and the community. Hub researchers worked with Traditional Owners, industry, community groups, non-government organisations and policy-makers to review the history, status and ecology of Australia's shellfish reefs, and develop methods to rebuild them.

Approach and findings

The Hub report, *Shellfish reef habitats: a synopsis to underpin the repair and conservation of Australia's environmental, social and economically important bays and estuaries,* outlined what Australia's shellfish reefs were like before their decline. This included the species they harboured, Indigenous use, and the value of ecological services provided in terms of fish production, water quality regulation, and coastal protection.

Shellfish reefs were confirmed as one of Australia's most threatened ocean ecosystems, with 90–99% of this once widespread habitat having disappeared. Dramatic losses followed harvesting for food and lime production, ecosystem modification, disease outbreaks and reduced water quality. Knowledge gaps and research priorities were identified, noting the need for evidence to be aligned with policy priorities and market incentives such as blue carbon.

The shellfish reef restoration process can generate employment opportunities, and established reefs can provide long-term economic gains for coastal communities, particularly in fishing, tourism and coastal protection. These benefits flow from services such as water filtration, prevention of coastal and wave erosion, and enhanced provision of food and habitat for other species.

Working with state biologists and non-government organisations, Hub researchers studied eight remnant Sydney rock oyster reefs (at Port Stephens, Richmond River and Hunter River, NSW, and North Stradbroke Island, Qld) and found they supported diverse and productive mobile invertebrate communities. Restoring such reefs was likely to boost habitat for these communities and local secondary production, supporting fisheries and a more resilient environment.

Consultation with Traditional Owners defined 'seven pearls of wisdom' to guide mutually productive partnerships for restoration. These included early and long-term engagement and project co-design and management; acknowledging Country and recognising Indigenous peoples' rights, responsibilities and knowledge; and linking coastal water quality with activities on land.

Outcomes and next steps

This work developed the knowledge and fostered the participation required to accelerate coastal habitat restoration actions by Australian governments, industries and communities. Evidence of national shellfish reef status underpins the nomination for native Flat Oyster and Sydney Rock Oyster reefs to be listed as Critically Endangered Ecological Communities under the *Environment Protection and Biodiversity Conservation Act 1999.*

Shellfish reef restoration projects underpinned by the team's research are now happening, funded in part by the Australian Government's Relief and Recovery Fund which allocated $20 million to restore up to 13 reefs in places including Albany, WA, the Sapphire Coast, NSW, Kangaroo Island, SA, and Noosa, Qld. Shellfish reefs are now part of Victoria's Biodiversity 2037 strategy and *Port Phillip Environmental Management Plan* and the *New South Wales Marine Estate Management Strategy.*

Future investment and community involvement in restoration can be encouraged by improving community understanding of the value of shellfish reef habitat; establishing reference sites at existing reefs; and building expertise and capacity in Australia's marine restoration community.

In 2020, project partners The Nature Conservancy, James Cook University, University of Adelaide and University of Tasmania were awarded the Eureka Prize for Applied Environmental Research.

TOP LEFT: **A blenny in shellfish reef habitat.** Image: Lisa Bostrom-Einarsson

TOP RIGHT: **Australian Flat Oyster reef at Georges Bay, Tasmania: the largest surviving healthy reef of its kind.** Image: Chris Gillies

BELOW: **An oyster farmer shows the dense colonisation reef-forming species associating with Sydney rock oysters on a spat settlement module in Pumicestone Passage, Queensland.** Image: Ben Diggles


Hitching a ride on Hercules: how oyster reefs form on mud banks in the absence of hard surfaces

While studying remnant oyster reefs at Richmond River, New South Wales, Hub project leader Ian McLeod of James Cook University and his team observed many Hercules club mud whelks with oysters growing on their shells.

Hercules whelks are common large marine snails on Australia's eastern coast. They grow to 100 mm in length and feed on detritus and algae that grow on mud. True to their name, they are foundational heroes of the oyster reef, yet with their strength comes the ultimate sacrifice.

"Some whelks carried up to four large oysters on their shell, and as the oysters grew larger, the whelks slowed and sank lower into the mud," Dr McLeod says. "We presumed this would eventually lead to the death of the whelk and the formation of a new oyster clump."

Dr McLeod and his colleagues were intrigued by the phenomenon because oyster larvae only settle on hard substrates. "The oyster shells then provide a settlement surface for reefs to grow on, with the oysters themselves providing chemical and sound cues that facilitate larval settlement," he says. "Such reefs often form on intertidal sand and mud banks, however. How can this be possible in the absence of hard surfaces?"

Solving such ecological puzzles is difficult because so few oyster reefs remain to study. Globally, oyster reefs have declined by 85% through destructive overfishing, coastal development, pollution, introduced competitors, predators and diseases. Hub research has shown that more than 90% have been lost in Australia. Active restoration is increasingly popular, including in Australia, but not always successful. Knowledge about how reefs naturally form and function is vital to improve success.

The team turned to the literature for clues, discovering historical newspaper accounts. One from 1891 noted: "bank oysters may attach to rocks, dead shell known as cultch or as more frequently, attach to the shell of the Hercules whelk, [...] and are ferried to various areas of the feeding grounds, until the whelk is overwhelmed and dies from the burden". In addition, an archaeological investigation into 1000-year-old Aboriginal middens in south-eastern Queensland found that seven percent of oyster valves probably had been hauled about by Hercules.

"We suspect Hercules whelks play a unique role for oysters as ecosystem engineers in sediment-dominated estuaries through epibiosis," Dr McLeod says. "Epibiosis is a relationship between two organism in which one lives on the other, but is not parasitic. In the absence of hard surfaces on mud banks, epibiosis provides the only way for oysters to expand into these habitats.

"Subsequent generations of oyster larvae can then settle on oyster shells creating a self-sustaining ecosystem, no longer reliant on whelks as substrate. The Hercules–oyster relationship is significant because it appears to be facultative for an entire ecosystem and not just individuals."

Epibiosis as a driver of ecosystem change is likely to be under-recognized in the marine environment. There are thousands of examples of marine epibiosis that range from barnacles growing on whales and microcolonisers such as bacteria and algal spores.

Gruesome examples include invasive Pacific oysters in the Dutch Wadden Sea, which have overgrown and replaced native Blue Mussel beds by settling on their shells. Pacific Oysters also grow on the shells of the periwinkles, reducing their ability to move and reproduce.

While the interaction between Hercules whelks and oysters is a similar process to these examples, the Hercules whelks and oysters are both native species in Australia. Therefore this is likely to be a natural process. This knowledge is important to restoring Australia's oyster reefs which are often replaced by 'bare' soft sediments.

This study showed the importance of understanding ecological processes including epibiosis, particularly in the context of the growing field of restoration. It also emphasised the importance of going beyond the contemporary scientific literature in a rapidly changing world to include historical context from scientific naturalists for baselines and understanding natural ecosystem function.

TOP LEFT: **Hercules whelks make an ideal hard substrate for Sydney rock oyster larvae to settle on, in otherwise slippery intertidal sediments.** Image: Pat Dwyer, New South Wales Department of Primary Industries

TOP RIGHT: **Dr Ian McLeod of James Cook University at a Leaf Oyster reef in Hinchinbrook Channel, Queensland.** Image: Ross Johnson

FURTHER INFORMATION
ian.mcleod@jcu.edu.au
Shellfish reef habitats report
Hitching a ride on Hercules

Tidal creeks in Tasmanian saltmarsh. Image: Vishnu Prahalad

Saltmarsh: a powerhouse of productivity

Australia's saltmarsh wetlands are listed as Vulnerable Ecological Communities under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999).

Saltmarsh wetlands drive coastal ecological productivity, and provide important habitat and food sources for commercial and recreational species including fishes and prawns. The ecological functioning of saltmarsh wetlands depends on connectivity between fresh and tidal waters. Along the Australian coast, however, they have been cleared, drained, filled and blocked with levees, bund walls and roads to exclude tidal inundation. Barriers to water flow and connectivity occur along almost every river and estuary in the more populated regions.

Reinstating tidal connectivity to ensure biological, chemical and hydrological fluxes is key to restoring ecosystem function and ecosystem services, and vital to the health of Australia's bays and estuaries. Restoring saltmarshes relies on support from governments, businesses and the community.

This Hub study identified changes and steps to restoring saltmarshes, and documented the potential value to fisheries productivity, to help foster improved community and agency understanding, investment and action.

Approach and findings

A national synopsis for saltmarshes covered habitat distribution, ecology and function, conservation status, and environmental, social and economic benefits. Saltmarsh repair strategies such as reconnecting tidal flows to boost habitat for prawns and fish were studied at Queensland's Burdekin floodplain, the New South Wales Clarence River estuary, and Circular Head in Tasmania. The tropical and sub-tropical studies used prawn species (potential increases in biomass) as indicators for estimating the benefits of repair. The temperate study focussed on dominant seafood/fish species of commercial and recreational interest.

The three diverse saltmarsh case studies demonstrated the substantial benefits that can accrue from reinstating ecosystem services such as fisheries productivity. Repair activities in most cases are relatively simple, involving minor earthworks to reinstate tidal connectivity and re-establish tidal channels. Benefits flowing from increased recreational and commercial harvests were estimated to exceed the costs of implementation.

Key challenges included the differing saltmarsh community types, knowledge base and legislation across different states, and a lack of community knowledge and appreciation of the value of saltmarshes. Furthermore, many of these areas are in private ownership. Nevertheless, Australia has some good examples and demonstrations of successful saltmarsh restoration that can underpin the scale-up of restoration activities.

Outcomes and next steps

This Hub study took steps to quantify the ecological and economic benefits that can accrue from saltmarsh restoration, using fisheries productivity as an example.

The case studies in different Australian saltmarsh environments provided baseline understanding relevant to the formulation of the proposed recovery plan for coastal saltmarsh listed under the EPBC Act 1999. They also raised community awareness and provided impetus and direction for policy and planning, conservation management, investment and on-ground action. Saltmarshes are being repaired in several New South Wales estuaries, including the Wooloweyah wetland in the lower Clarence River estuary.

Key steps to foster understanding of saltmarsh repair include identifying the function that needs restoration (such as tidal connectivity), selecting tangible indicators (such as prawns and fish); collecting relevant biological information and developing candidate scenarios for repair.

FURTHER INFORMATION

vishnu.prahalad@utas.edu.au

Repairing and conserving Australia's saltmarshes

Expanding fish productivity in Tasmanian saltmarsh wetlands

Worth their salt

Studies at Circular Head in Tasmania and the Clarence River estuary in New South Wales took steps towards quantifying the benefits of saltmarsh restoration.

Circular Head Saltmarsh has been degraded by levee works, ditching, clearing and grazing. Hub researchers looked at how the saltmarsh is used by fish. They found 11 fish species, with a high mean density of more than 72 fish per 100 m². Commercial and recreational species included Yellow-eye Mullet, Australian Salmon and Greenback Flounder.

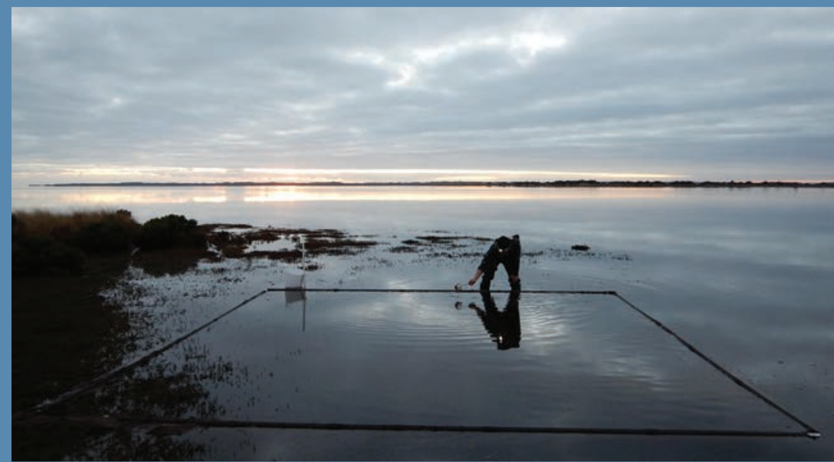
Water depth had a strong effect on fish density and richness, and restoring tidal flows anywhere across the region was considered likely to expand beneficial fish habitat. Priorities would be to protect Boullanger Bay and Robbins Passage, and rehabilitate the buffering paperbark swamp forests.

Clarence River estuary once featured more than 100 islands, but the extensive wetland habitats, have been drained, primarily for agriculture, severing arteries that might support fishery productivity.

A fishery model was used to assess the potential benefits of reconnecting the shallow sub-tidal creeks that once fed Lake Wooloweyah in the lower estuary. The modelling predicted an annual boost to School Prawn fishery production of $900/ha in marsh habitat and $5000/ha in channel habitat. Other species would also benefit, including Mud Crab, Dusky Flathead, Yellowfin Bream, Luderick and Sea Mullet. The next step is to apply these estimates across the estuary. The results, combined with investigations of flood management, catchment hydrology, full economic costs and benefits, engineering works and social feasibility could underpin the estuary's repair.

Migratory birds in Tasmanian saltmarsh. Image: Vishnu Prahalad

High tide fish habitat in Tasmanian saltmarsh. Image: Vishnu Prahalad



Testing the effect of saltmarsh habitat fragmentation on fish species diversity and density at Circular Head Saltmarsh. Image: Vishnu Prahalad

Hardyheads visiting a tidal creek in a Tasmanian saltmarsh. Image: Vishnu Prahalad

Success with culturing and outplanting giant kelp

South-eastern Australia's giant kelp marine forests are listed as a threatened ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* due to progressive losses largely associated with climate change.

These communities are an important part of the temperate rocky reef systems that support our unique marine biodiversity and high-value commercial, recreational and Indigenous fisheries. Active restoration of disappearing giant kelp forests represents one approach for their conservation. However, any restoration effort must consider the ongoing challenges and threat of ocean warming, which is a key driver of giant kelp forest loss. This Hub project aimed to examine whether more thermally-tolerant giant kelp 'genotypes' existed among remnant giant kelps, and if so, to assess the use of warm-tolerant family-lines as the foundation of potential restoration efforts.

Approach and findings

Reproductive material was non-destructively collected from 50 individual giant kelp across six remnant forests in eastern and southern Tasmania (these regions are the former stronghold of the species in Australia). These samples were used to establish giant kelp cultures in the lab, and create of one of the world's first giant kelp 'seed banks'. Samples were taken from each of the 50 giant kelp cultures, and the resultant juvenile kelp were grown under a range of seawater temperatures.

All the tested giant kelp family-lines grew well at 12°C and 16°C, which are typical seawater temperatures in Tasmania. At warmer temperatures of 20°C, the majority of family-lines perished, however ~10% of the tested kelp survived and grew well at these temperatures. Surprisingly, some family-lines even survived at temperatures as high as 24°C. The family-lines identified to be more warm-water tolerant were bred in large quantities, and the resultant juvenile giant kelp outplanted at the three trial restoration sites. Two methods were trialled for outplanting, with the microscopic juvenile kelp seeded onto thin lines wrapped around elasticated cords or onto small plastic plates that were then bolted to the rocky reef within the patches.

Selected giant kelp family-lines were planted at three Tasmanian trial sites to test various methods of outplanting, and the survivorship of lab-grown giant kelp in the field. The ultimate goal of outplanting was to establish self-sustaining (and potentially self-expanding) patches of giant kelp. When the giant kelp restoration sites were revisited in early 2021, one showed excessive sedimentation and growth of filamentous turf algae, but no surviving giant kelps. The other two sites were highly successful in terms of the number, growth, size, and health of giant kelps in the restoration area. The kelps were growing vigorously at high density from the microscopic outplants.

Outcomes and next steps

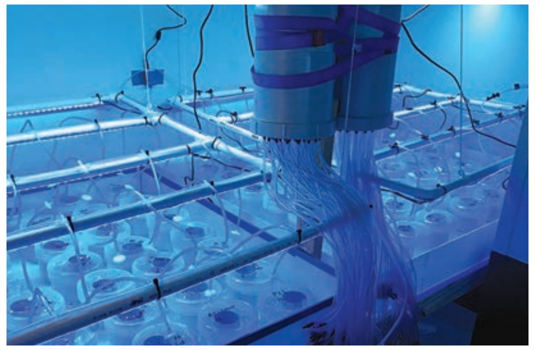
This project generated increased interest and public awareness about the status and loss of giant kelp forests in Tasmania, and new understanding about the complex life cycle and cultivation of giant kelp, providing a platform for future breeding and selection programs and the refinement and upscaling of restoration.

Giant kelp that are more tolerant of warm water have been identified within remnant populations providing hope and the potential to 'future-proof' restoration efforts.

Outplanting methods continue to be refined, providing invaluable guidance to the transfer of the giant kelp from the lab to the field. Additional work, initially unplanned, led to the development of long-term low-maintenance storage methods and a 'seed bank' for Tasmanian giant kelp. This will aid future restoration efforts and also provides genetic conservation of remnant giant kelp.

FURTHER INFORMATION
cayne.layton@utas.edu.au
Assessing the feasibility of restoring giant kelp forests

BELOW: **Gametophyte cultures are exposed to blue light for a week or so to promote fertilisation. The lights are then changed to white for the grow out stage.** Image: Cayne Layton

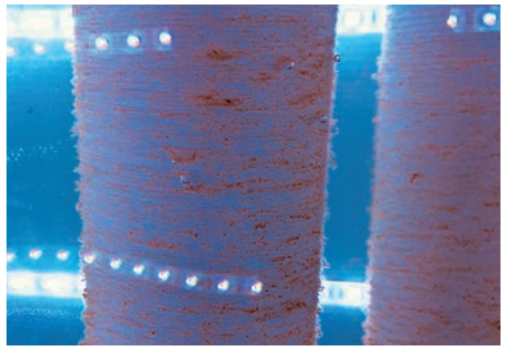


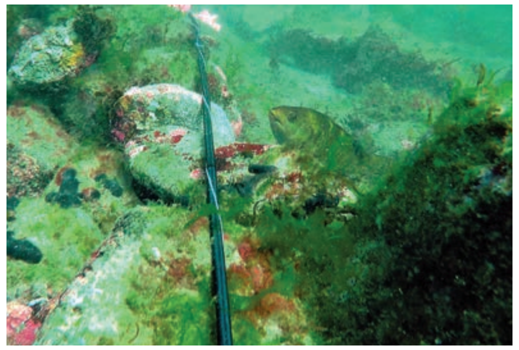
MAIN IMAGE: **One of many healthy giant kelp outplanted at a restoration trial site. After 14 months, some plants had grown to more than 12 m tall. The average height was about 3 m.** Image: Cayne Layton

BELOW LEFT: **A spool of kelp-seeded twine in the lab, showing one method of how the kelp are cultivated before being planted.** Image: Cayne Layton

BELOW CENTRE: **The project tested several different methods of planting the kelp, including this early trial that used seeded twine and elasticated cord.** Image: Cayne Layton

BELOW RIGHT: **The root-like holdfast of one of the planted kelp, showing how giant kelp grow and attach to the rocky reef.** Image: Cayne Layton





Wire Weed seedlings spend several weeks to months floating with the currents and tides, before eventually sinking to the seafloor and catching hold of something to grow on. Image: Rachel Austin**.**

Working together to restore wirriya jalyanu (seagrass) at Gathaagudu (Shark Bay)

Western Australia's Shark Bay World Heritage Area – known as Gathaagudu to Malgana Traditional Owners – harbours some of the largest seagrass meadows in the world.

The seagrasses support the biodiversity of Shark Bay, including commercial, recreational and Indigenous harvests and World Heritage values. During a marine heatwave in the summer of 2010–2011, sea temperatures spiked 2–5°C above long-term averages, devastating more than 1300 km² of seagrass meadows. The losses affected culturally significant species including Green Sea Turtles (Buyungurra), Dugong (Wuthuga), cormorants (Wanamalu) and Bottlenose Dolphins (Irrabuga). Two large temperate seagrasses – *Amphibolis antarctica* (Wire Weed) and *Posidonia australis* (Ribbon Weed) – tend to recover slowly, and this raised the need for assistance.

In this project, Hub researchers partnered with Malgana Rangers to allow traditional knowledge and skills focused on managing Country to be integrated with western science. Together they developed a restoration framework to assist the natural recovery of seagrasses in preparation for future impacts of climate change.

Approach and findings

In four training workshops, the rangers and researchers developed and trialled simple, cost-effective methods to assist the recovery of Wire Weed and Ribbon Weed. Suitable plants and seedlings for restoration were selected according to their genomic diversity and adaptive traits, and different restoration methods were applied to the plants at different growth stages (seeds, seedlings, and adults). The rangers also completed conservation and land management training, which included seagrass habitat restoration.

The two most successful restoration methods tested were harvesting, processing and replanting adult shoots of Wire Weed and Ribbon Weed, and deployment of sand-filled, biodegradable hessian tubes called 'seagrass snaggers' to facilitate the natural recruitment of Wire Weed seedlings. The tubes were best deployed just before seedling release, and oriented perpendicular to current flow.

Studies of genetic structure among Ribbon Weed meadows found that a single, widespread, clone spanned at least 180 km. This widespread clone also had twice as many chromosomes than oceanic meadows. Whole genome duplication through polyploidy has apparently increased temperature and salt tolerance, thus enabling the single clone to expand through vegetative growth across Shark Bay's extreme environmental gradient.

Measuring the success of restoration activities takes time (years rather than months) and requires multiple visits, particularly for the larger temperate species. The first two years are critical for seagrass establishment and individual transplant survival, shoot counts, percentage coverage and growth rates should be monitored at least every 3–6 months. This information is needed to assess the success of restoration and the need for supplemental planting.

In October 2020, researchers measured the return of ecosystem function at several restoration sites established through traditional transplanting of adult plants. Some sites were planted in 2015 and 2018 (before the Hub project) and two new sites were established with Malgana Rangers in March 2020. There was expanded cover and increased shoot density at the older restoration sites. Fish diversity was highest in the oldest Wire Weed sites, and the survival of transplants was very high in the two Malgana Ranger sites, with lots of new Wire Weed shoots.

A particularly rewarding part of this project was the relationship developed between Hub researchers and Traditional Owners to enable long term partnerships with the Malgana People and their Ranger Program. Initial project ideas were conceived through early conversations on Country in August 2018. More than two years of continued participation and knowledge sharing fostered methods tailored to local environmental conditions, skills, and working in a remote location such as Shark Bay.

The joint organisation of the Wirriya Jalyanu (seagrass) Festival at Denham provided an opportunity to celebrate the ecological and cultural value of seagrasses, strengthen relationships, and discuss the training workshops and restoration framework. Science talks provided context for the Festival activities which included science, archaeology, cooking, art, dance, land management, and Malgana language.

Outcomes and next steps

This project determined the cause extent of seagrass losses, and developed a framework for nature-based restoration that presents a solution to the effects of climate change on seagrasses in the Shark Bay World Heritage Area. It demonstrated that with the right resourcing and logistic support, there are opportunities to fund both training and broad scale restoration by working closely with the Traditional Custodians of the land.

The Hub team learned that time needs to be spent building relationships On Country – friendships, trust, and openness to share knowledge – before entering into a working project. Also, the funding models and timeframes typically set for western science do not fit well with indigenous engagement. Additional time is needed for communication, approvals and decision making between Indigenous participants and agencies, Elders, and researchers. Malgana Rangers are developing the capacity to partner in on-ground activities and the Malgana Aboriginal Corporation is keen for seagrass research and monitoring to continue. These activities depend on future funding for Ranger positions.

There are prospects for large-scale deployment of 'seagrass snaggers' to facilitate Wire Weed seedling recruitment. Future monitoring could assess changes in animal communities and carbon storage in the sediments of replanted sites. Reference meadows should be selected, with 75% cover or greater, to assist in monitoring the recovery of nearby restoration sites.

TOP LEFT: **Signs of returning ecosystem function. Butter fish explore a 2.5 year old Ribbon Weed restoration site.** Image: Rachel Austin

TOP RIGHT: **Researchers and Malgana Indigenous rangers head out to explore seagrasses at Fowlers Camp, Shark Bay.** Image: Rachel Austin

FAR LEFT: **Defoliation of Wire Weed following the marine heat wave.** Image: Matthew Fraser

LEFT: **A healthy Wire Weed meadow.** Image: Matthew Fraser

FURTHER INFORMATION

john.statton@uwa.edu.au

elizabeth.sinclair@uwa.edu.au

Assisting seagrass recovery in Shark Bay

Seagrass snagging

'Seagrass snaggers' are long hessian socks filled with local beach sand. They are placed on the seafloor to snag and retain Wire Weed seedlings. Ninety seagrass snaggers were deployed in two locations at Gathaagudu, close to existing Wire Weed meadows. The snaggers should last about 18 months before the hessian (and wire) naturally break down: long enough for new seedlings to establish. This method is simple, cheap, and easy, but timing is critical. The snaggers must be in place before the major release of seedlings begins. July to September is peak dispersal time for budding Wire Weed seedlings. Ongoing work by Malgana Rangers means snaggers in coming seasons can be appropriately timed.

BELOW: **Malgana Ranger Nick Pedrocchi and UWA researcher John Statton deploy a seagrass snagger.** Image: Gary Kendrick

BOTTOM: **Two months after deployment, the snaggers are embedded in the sandy bottoms, and have begun to collect dispersing seedlings.** Image: Gary Kendrick

Image: Rachel Austin

Sharing Malgana culture

Malgana peoples have lived at Gathaagudu (Shark Bay) for about 30,000 years.

Rising sea levels from the end of the last ice age mean that much of Malgana Country is now drowned, with cultural heritage preserved under the extensive seagrass meadows that thrive in the shallow waters.

Stories have been shared by Malgana Rangers about their ancestors walking from Denham to Wirruwana (Dirk Hartog Island), and Bernier and Dorre Islands across the sandy bottom or at low tides, and knowing where the freshwater seeps were located. Much of this submerged heritage is yet to be explored.

Buyungurra

The turtle, buyungurra, well he used to live on the land a long time ago. And how it got from being on the land to being in the sea was because it was chasing these particular berries.

These were some berries or seeds washing out to the ocean.

The turtle was eating these things and all the other animals said to it not to keep chasing the berries because it would end up in the ocean forever, in the deep forever. But that turtle, it kept ignoring, kept ignoring, kept ignoring, and now it's in the ocean forever.

And that's why the shape of this particular kind of berry looks a little bit similar to the turtle shell. So when people see the shell, they say that's they berry that came up, you see, and that's what happened.

… was this berry a floating Posidonia fruit?

The 'Buyungurra' story was told by Auntie Topsy Cross, one of the last Malgana speakers, to a young friend who recounted it as best he could. It was reproduced with permission of the Malgana Working Group in Tindale (1966).

Malgana words

Nyinda wula wujanu, nyinda yajala	You come a stranger, you leave a friend
Duthuduguda	Broadhurst Bight
Thaamarli	Tamala Station
Wilyamaya	Tip of Heirisson Prong
Wirruwana	Dirk Hartog Island
Wulyibidi	Peron Peninsula
Muga	Middle Bluff
baba	rain
barraja	land
birrida	salt pan
boolagooda	stromatolites
buyungurra	turtle
buthurru	sand
djiljit	fish
gurab	crab
irrabuga	Bottlenose Dolphin
jurruna	pelican

mardirra	pink snapper
muga	deep water
mulgarda	mullet
mulhagarda	whiting
thaaka	shark
thalganjangu	tidal pool, lagoon
wabagu	sea eagle
wanamalu	cormorant or shag
warda	pearl
wilya	shell
wilyaa	seagull
wilyara	pearl shell
winthu	wind
wirriya	sea, salt water
wirriya jalyanu	seagrass
wuthuga	Dugong

Estimating the costs and benefits of restoration

Worldwide interest is growing in the restoration of lost and degraded coastal and marine habitats, from saltmarshes to shellfish reefs.

The ability to evaluate the risks, costs and benefits across a range of restoration contexts is pivotal to successful, cost-effective restoration projects. Evaluations need to consider the full range of tangible (market) and intangible (non-market) costs and benefits across a range of alternative management approaches, spatial scales and habitat types.

Approach and findings

This Hub research used an economic benefit-cost analysis approach to construct a framework for estimating the viability of shellfish reef repair projects. The framework integrates the environmental, social and economic outcomes of a restoration project and provides quantitative decision metrics for use in evidence-based decision making and the justification of funding support.

A case study focussed on Windara Reef in South Australia determined that significant environmental and economic benefits would flow from restoration, including increased use by interstate recreational fishers. Community engagement to promote Windara Reef was considered important to securing the predicted recreational fishing benefits.

Investment in ongoing monitoring to capture baseline data on the actual environmental and recreational fishing benefits was recommended. The cost of collecting the data was small, and it would improve future understanding of the benefits, costs and risks of shellfish reef restoration to generate greater confidence in the economic evaluation of biophysical and social outcomes.

Outcomes and next steps

An integrated economic framework approach demonstrated that habitat restoration can provide 'co-benefits' additional to environmental objectives, including opportunities for economically profitable outcomes.

The Australian Government, state and territory governments, marine industries and non-government organisations are better equipped to make decisions about how to invest in regional coastal and marine habitat restoration and planning, monitoring and review. This is fundamental to Ramsar site management, and to recovery planning and activities for threatened shellfish reef ecological communities under the *Environment Protection and Biodiversity Conservation Act 1999.*

FURTHER INFORMATION
abbie.rogers@uwa.edu.au
Benefit-cost analysis for marine habitat restoration

Economics favours Windara Reef extension

Windara Reef in Gulf St Vincent, South Australia, is the largest underwater marine habitat restoration attempt made in Australia to construct a native oyster reef. The total cost of the project was $3.4 million, with funding shared by The Nature Conservancy and three tiers of government.

The Hub's integrated economic assessment of market and non-market values associated with reef restoration supported the 16-hectare Windara Reef Stage Two extension. The benefit-cost analysis framework included the tangible, market-based outcomes and also the intangible, non-market social and environmental outcomes of the reef construction. This included construction and operating costs; environmental benefits related to improvements in biodiversity and ecosystem functioning; intrastate and interstate recreational fishing benefits; educational tourism; profit to oyster suppliers and charter operators; and potential benefit to commercial fishers.

Shellfish reef restoration brings significant environmental and economic benefits.
Image: Paul Hemer

Building national understanding and capacity

Nine categories of matters of national environmental significance (MNES) are protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

To date, restoration has not been a commonly used conservation strategy within the context of MNES in coastal and marine areas. Most effort has focused on habitat protection and removal of stressors.

A Hub study reviewed the capacity for coastal restoration to reduce conservation risks associated with MNES, to help build a shared understanding of how restoration activities may be applicable under national environmental law.

The Hub also worked with research partners to establish and facilitate national forums to connect people and groups with knowledge, interest and involvement in coastal restoration.

Approach and findings

Matters of national environmental significance

The role of marine and coastal restoration in conserving MNES was examined for four habitat types: giant kelp forests, seagrass meadows, saltmarshes and shellfish reefs. Each habitat was demonstrated to fall under up to six of the nine MNES categories.

These are: listed and threatened species and communities, listed migratory species, Commonwealth marine environment, Ramsar wetlands of international importance, world heritage properties, and the Great Barrier Reef Marine Park.

Restoration was identified as a relevant and useful conservation approach for managing Australia's valuable marine and coastal habitats, while also providing employment and economic development opportunities. Investment in national and regional leadership, including a formal network for connecting people and knowledge sharing was considered important to building momentum.

Australian Coastal Restoration Network

The Australian Coastal Restoration Network (ACRN) is a national platform for researchers, practitioners and managers to connect, collaborate, share knowledge and ideas, and seek assistance. The network was born in 2017 at the Inaugural Australian Coastal Restoration Symposium facilitated by the Hub and research partners. It has since hosted national and international restoration meetings and conferences, workshops and networking events. Newsletters were circulated to more than 400 subscribers, and some 700 inquiries were fielded. The Hub also supported three national groups: the Shellfish Reef Restoration Network, the Seagrass Restoration Network, and the Mangrove and Saltmarsh Network.

The ACRN developed a database covering all marine and coastal restoration projects in Australia. The Australian and New Zealand Coastal and Marine Ecosystems Restoration Database includes more than 200 case studies which can be explored by ecosystem type and location.

Outcomes and next steps

This project contributed to the evidence base for the National Reef Builder Project: a partnership between the Australian Government and The Nature Conservancy to bring shellfish reefs back from the brink of extinction.

With more than 280 members, the ACRN has enhanced Australia's national capacity to connect and enable people who have an interest in coastal restoration. This capacity provides leadership and supports efforts by the Australian Government, state and territory governments, non-government organisations, marine industries and communities to conserve, restore and manage the ecosystem services these habitats provide to society.

More than 60 coastal restoration professionals attended the Coastal Restoration Symposium.

FURTHER INFORMATION
ian.mcleod@jcu.edu.au
The role of restoration in conserving MNES

Advancing national approaches for data delivery

Stereo BRUV ready to collect data at Ningaloo Reef.
Image: The University of Western Australia

Joining the dots: adding value to marine environmental data

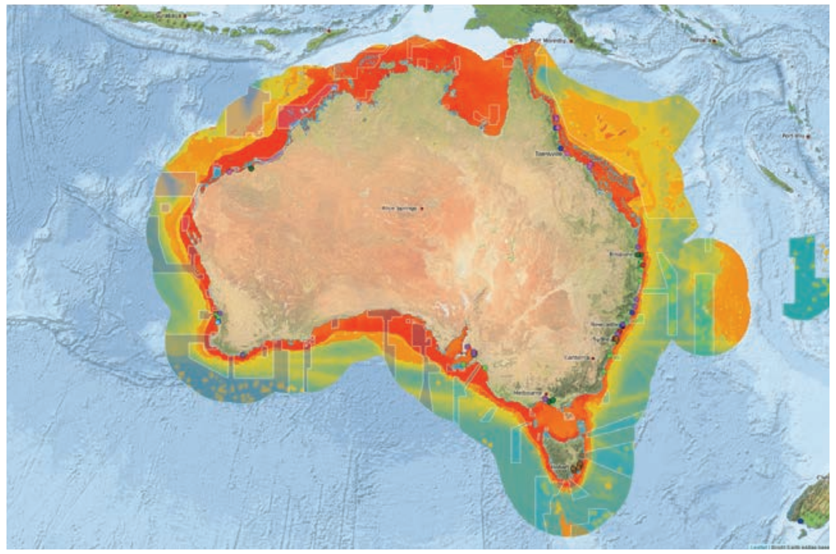
When scanning the property market or checking the weather, we all want timely, curated and accurate data presented in ways that help us make confident choices. It's the same for people making decisions about sustainable use and biodiversity conservation.

Managers, researchers, research users and custodians of the marine environment need relevant, searchable and scalable data at their fingertips. In many cases, however, data are collected and stored in disparate ways by multiple agencies, industries, and initiatives. This makes the data landscape difficult and confusing to navigate.

As Australia's leading national collaboration for marine biodiversity research data, the Hub provided leadership for advancing common approaches to data collection and sharing. There were key imperatives that the Hub was uniquely positioned to tackle, and our tentacles spread far and wide.

Hub researchers and leaders championed FAIR (findable, accessible, interoperable, reusable) data principles among the marine science community and data users by:

- developing relationships that fostered a culture of data sharing;
- building and contributing to national repositories that aggregate and streamline data and information to facilitate evidence-based decision-making; and
- established best-practice approaches to acquiring and processing data (see story on page 92).



Intensity of cumulative pressures on benthic ecosystems, overlaid with the location of habitat restoration projects. Image, Seamap Australia

Hub projects focused on the needs of a broad cross-section of users, traced and tailored existing data to support management and research planning, and brought together partners and collaborators to collect data in new areas (see Section 1). The enhanced data provision achieved by these initiatives brought new and innovative levels of support for effective assessment, monitoring and management of Australia's marine environment.

Connecting data to build understanding

Through its research partnerships, the Hub played a pivotal role in identifying, 'liberating' and collating nationally important datasets. Hub studies assembled existing data and information for reefs on the Australian continental shelf, and for reef biodiversity in 31 temperate Australian Marine Parks (AMPs). Datasets harnessed by these studies provided a cohesive evidence base for decision-making and identifying research needs. The studies also helped to catalyse the establishment of data collection and processing standards, and centralised map-based discovery and access portals such as Seamap Australia and AusSeabed.

Data collation projects in northern Australia enabled predictive mapping of seafloor habitat and biodiversity in Oceanic Shoals Marine Park, and regional distribution and habitat mapping for threatened and migratory species (see story on page 33). Life history data compiled for Largetooth Sawfish provided the basis for population assessments (see story on page 57).

A national working group coordinated by the Hub focussed on the role of biological data collected by baited remote underwater stereo video (stereo-BRUV), particularly in AMPs. The group implemented GlobalArchive, a web-based tool for centralising stereo-BRUV annotation data in a standardised, synthesised national collection, and paved the way for research agencies and universities to contribute. The extensive fish annotation database is an important resource for assessing and monitoring shelf reef fish communities. Managers and researchers can assess the efficacy of measures such as no-take zones, and the impacts of pressures such as fishing and climate change.

Pressure on the marine environment was another strong focus of data collation (see Section 2). National pressure data dating back 30 years were collated for multiple activities such and fishing, shipping activity, seismic surveying, and oil and gas production. The National Outfall Database project gathered data from local and state monitoring authorities for 194 Australian coastal outfalls, providing a nationally cohesive database of effluent quality, and a framework for standardised wastewater reporting. A review of ship-strike risk to whales, dugongs, turtles and dolphins supported a national strategy review, and the mapping of cumulative shipping noise will guide future considerations of mitigation and risk management.

Creating knowledge for decision-makers

Marine data portals proliferated during the period of the Hub, fed by an explosion in the quantity and quality of new data and an increasing need for easy, rapid, and consistent access to data. The Hub brought together data providers and research users to showcase and clarify the roles of each portal. This unprecedented overview was a crucial step towards national coordination. Users and developers focussed discussions on moving toward complementary, interoperable and fit-for-purpose portals, with the aim of making Australia's marine data discoverable and accessible to all.

Map-based data portals facilitate knowledge transfer by allowing research users to visualise and explore spatial data in ways that are impossible with static datasets or reports. They can overlay data from various sources, view at different resolutions, see patterns, weigh options, and export maps for communication and reporting.

Our advocate for open data

As the Marine Biodiversity Hub data manager, Emma Flukes of the Institute for Marine and Antarctic Studies, University of Tasmania saw her role as smoothing the way between researchers and technical (data) specialists.

After auditing datasets from Hub projects, she developed guidelines to help researchers publish their data through the Australian Ocean Data Network. She also helped to tailor Hub data and knowledge to meet the needs of research users.

Dr Flukes approaches data management from the perspective of a community ecologist. Her PhD research looked at the effects of climate change on habitat-forming kelps and rocky reef communities, and she has also studied overgrazing by the long-spined sea urchin. Now her fascination for ecology is fulfilled by currents of open data.

"I was really excited to work with the Hub, which had the policy of making all its data publicly available as quickly as possible," Dr Flukes says. "I hope more and more researchers will recognise the benefits.

"Open data systems require some effort to get up and running, but once the wheels are turning they hugely decrease the overall effort that goes into collecting and showcasing data. This enables a faster and more efficient path to scientific discovery, encourages collaboration, reduces duplication of research efforts, and can even boost citation rates.

"Another advantage is that researchers can keep track of who is using their data, and this can lead to collaboration. Studies have shown that making data open access results in, on average, a 30% increase in citations of associated publications, in addition to direct data citations.

"In fact data themselves can now be cited. Datasets from Reef Life Survey – a global project supported by the Hub for its national work – were some of the first to be published, in the first edition of the *Nature* journal *Scientific Data*."

Dr Flukes says the ultimate user experience will be to display all kinds of data for a particular area – images, videos, model output, empirical measurements – on an integrated map. This has the added power of highlighting well-known areas, and 'black holes' for data collection.

Emma Flukes.

The Hub encouraged the marine research community to make datasets available through Web Services, a technology that allows data sharing and interoperability with mapping software, portals, and analysis tools. This enabled important links with Seamap Australia, the Australian Marine Parks Science Atlas, and internal mapping systems used by the Department of Agriculture, Water and the Environment.

Hub partners explored pathways for portals to adopt standard Open Geospatial Consortium and ISO (International Organization for Standardization) compliant protocols for metadata and data sharing. These interoperable standards allow human and machine-readable access to marine data, ensuring consistent and standards-based delivery of information controlled by the custodian. Case study applications were designed to complement existing map-based portals such as Seamap Australia. Hub researchers also progressed the technical aspects of providing raw imagery data through map-based portals by working closely with national initiatives such as the Understanding Marine Imagery program facilitated by the Integrated Marine Observing System.

Putting data to work

Hub projects contributed data to support a range of national initiatives such as State of the Environment (SoE) reporting, adaptive management of AMPs, and a plan of action for conserving Australia's sharks and rays.

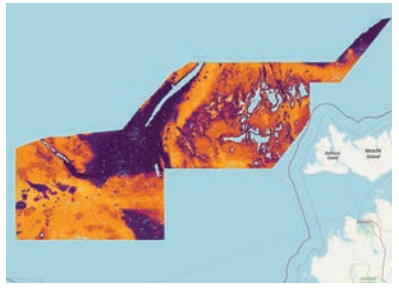
The Hub data manager worked with SoE authors to ensure that expert assessments and underlying data and information for the marine chapter linked seamlessly to the Australian Ocean Data Network. This provides a public archive, and a foundation for eventual linking to dynamic data sources that can be used to generate regular updates (for selected analyses) to support future reporting. It is central to ensuring SoE marine reporting is transparent, repeatable, and based on the best available information. The 2021 SoE assessment of marine and coastal biodiversity trends relied on national integration and analysis of data from Australia's three largest ongoing ecological monitoring programs for shallow water species (see story on page 44).

A project with Parks Australia developed a method for identifying monitoring priorities for AMPs. Natural values mapped for the South-east Marine Parks Network were assessed for their vulnerability to pressures, helping AMP managers visualise the features we value most and the benefits they provide, and where human activities pose the greatest ecological risk. This was part of a system developed to identify gaps and prioritise future data collection across these vast and difficult to access environments (see story on page 24).

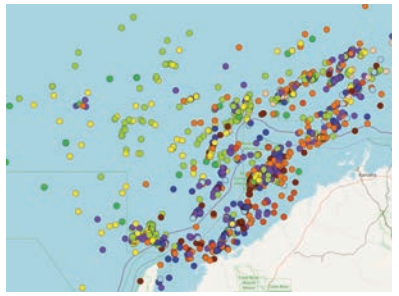
The Action Plan for Australian Sharks and Rays 2021 provided the first comprehensive assessment of extinction risk for Australia's 328 sharks, rays, and chimaeras, giving managers and stakeholders a shared understanding of the extinction risk of Australia's shark populations. The Action Plan is fundamental to ensuring the evidence underpinning the EPBC Act is as up to date as possible in protecting threatened sharks, rays, and chimaeras. The Australian Government as well as state and territories can identify priority at-risk species, species that may need future protection, and species of no immediate conservation concern.

Selected datasets collated by the Marine Biodiversity Hub, as displayed on Seamap Australia.

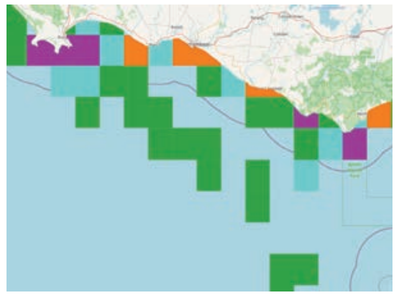
ABOVE: **Geomorphology of seamounts in the Coral Sea.**



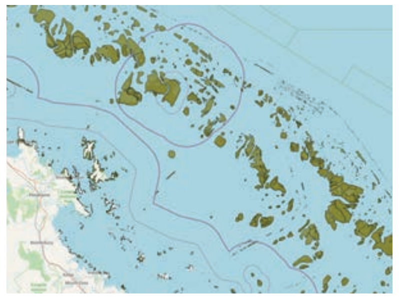
Predicted pelagic vertebrate density in Oceanic Shoals Marine Park (darker purple: greatest density; lighter yellow: least density).



Petroleum and gas wells off north-western Australia, 2016 (drilled since 1955).



Rock lobster fishing effort off south-eastern Victoria 2011–2015.



Reefs on the Australian continental shelf, east of Mackay to Townsville, Queensland.

Image: CSIRO Marine National Facility

National marine data portals: steadying the view

Several online portals have been developed to collate and present national and international marine research data. The Hub endeavoured to improve data delivery through these portals in ways that meet the needs of researchers and research users.

Australian Ocean Data Network: **The Hub ensured all its research data outputs were well described and accessible through the Australian Ocean Data Network (AODN) catalogue and other national research repositories such as Research Data Australia. More than 120 Hub data collections are catalogued on AODN, including a significant body of internationally relevant biological data. The Hub also worked with AODN to help improve cataloguing and access to biological data, and delivery to marine managers, decision-makers and researchers.**

Seamap Australia: **The Hub worked on the conception and development of Seamap Australia, in partnership with the Institute for Marine and Antarctic Studies, University of Tasmania. Seamap Australia built on national seabed habitat mapping projects initiated by the Hub, such as the collation of data for continental shelf benthic reef habitat. Seamap Australia is making progress in this arena through an Australian Government-funded Our Marine Parks Grants project.**

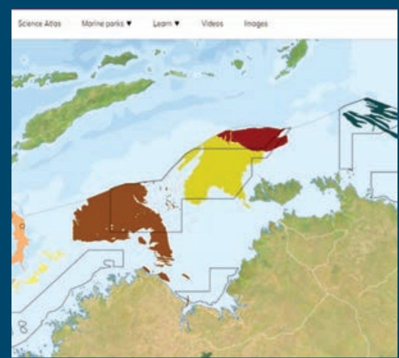
For example, consultation with Parks Australia highlighted the potential to greatly improve the efficiency of management decisions by linking Seamap Australia with other data providers such as the Integrated Marine Observing System (IMOS), AusSeabed, CSIRO (pressures data), the National Reef Monitoring Network and the Atlas of Living Australia. This would give Australian Marine Park managers a rapid visual summary of known research and other activities in a particular area, including bathymetry mapping, habitat imagery and species distributions. Seamap Australia and the PA-funded Our Marine Parks project have since made progress in this arena.

Squidle+: **The Hub generated a large volume of seafloor imagery via the use of the IMOS AUV facility and other platforms. Squidle+ is a powerful online tool for managing, exploring, and annotating georeferenced marine images. Hub researchers worked closely with the AODN to improve processing protocols to ensure imagery collected on voyages of national interest are delivered in a timely manner to Squidle+. This enabled consistent, efficient, and repeatable transformation of underwater imagery into quantitative information for researchers and managers.**

Australian Marine Parks Science Atlas: **The Hub worked with Parks Australia and the Australian Institute of Marine Science (a Hub partner) to provide scientific content for the Australian Marine Parks Science Atlas. This content included spatial datasets, project findings, imagery and 'eco-narrative' reports that summarise existing knowledge for AMPs.**

Spotted Handfish survey locations near Hobart, a spatial dataset provided on the Australian Ocean Data Network.

A national view from Squidle+ showing the locations and numbers of datasets available from a range of visual sampling platforms.



Key ecological features (KEFs) displayed by the Australian Marine Parks Science Atlas. Hub research contributed to the definition of KEFs such as the Carbonate bank and terrace system of the Van Diemen Rise (dark yellow), Tributary canyons of the Arafura Depression (dark blue-green) and the Ancient coastline 125 m depth contour (light yellow).

Marine sampling best practices a vital step to national and international monitoring

Nationally coordinated marine research to support assessment, monitoring and management is a shared responsibility that requires consistency in the collection of environmental and biodiversity data.

The Hub led the development and adoption of best practices that ensure marine data collected at different times and places around Australia are directly comparable.

The best practices are outlined in the Hub's *Field Manuals for Marine Sampling in Australian Waters.* They set standard procedures for operating commonly used sampling gear such as multibeam echosounder, baited remote underwater stereo-video and autonomous underwater vehicles. They cover the full survey process, from planning and data acquisition, to data management and reporting, and support the efficient use of survey time and resources.

It was vital for the best practices to be developed collaboratively, so the Hub team tapped into the desire of most researchers for robust, well-documented data collection, and sought advice from research, government, regulatory and commercial agencies. Ultimately, 136 individuals from 53 organisations were involved in the extensive consultation and review process.

Uptake of the best practices has been enthusiastic, with many national agencies onboard, and interest from international research programs. They have been endorsed by Parks Australia, the National Offshore Petroleum Safety and Environmental Management Authority, the Global Ocean Observing System and the Ocean Best Practices System. Here is a selection of perspectives on the value and challenges associated with the best practices, gathered from members of the Hub community.

Time for governance framework

"We have been blown away by the uptake and response to marine sampling best practices. We think this is due to our highly collaborative and iterative approach. We are now at the stage where we need to look to the future. What is going to happen with these best practices? Who will maintain them? Who will decide when we need new ones? How can they be linked to other national initiatives? The time seems right for an overarching governance framework to manage such questions and ensure we can continue to deliver the most efficient and fit-for-purpose data to manage Australia's beautiful marine estate."

*Project co-leader, **Rachel Przeslawski,** Geoscience Australia and New South Wales Department of Primary Industries*

Monitoring is more than surveys

"While monitoring is the tool for gathering objective knowledge (especially about trends), it is more than just a series of surveys. To enable effective monitoring, data collection needs to be coherent and standardised to support evidence-based decision-making. Standardisation also reduces extraneous variation, increasing the amount of accessible information contained in data."

*Project co-leader and survey design best practice team leader, **Scott Foster,** CSIRO*

Taking our best practices overseas

"In 2019 I visited the Caribbean island of St Lucia to guide researchers and fisheries officers in the use of baited remote underwater stereo-video (stereo-BRUV). The initiative was facilitated by the United Kingdom's Centre for Environment, Fisheries and Aquaculture Science (CEFAS), which supports marine biodiversity mapping and monitoring worldwide. I trained staff from CEFAS and the St Lucian Department of Fisheries based on our best practices, which we applied during 10 days of fieldwork in marine protected areas."

*Autonomous and remote underwater vehicles best practices team leader, **Jacquomo Monk,** Institute for Marine and Antarctic Studies, University of Tasmania*

TOP: **Jacquomo Monk applied the marine sampling best practices during surveys at St Lucia.** Image: Centre for Centre for Environment, Fisheries and Aquaculture Science

LEFT: **Project co-leaders Scott Foster and Rachel Przeslawski.**

Maximising the value of data

"Seafloor mapping is a big investment in equipment, skills and ship time, so we need to build efficiencies and collaborations that maximise the quality and value of our data. The manuals will help to streamline and bring clarity to all stages of the research process, bridging gaps between the people who fund, collect, process and use ocean data. We'll spend less time on data processing, and provide more rapid, multidisciplinary responses to contemporary questions, plus accessible, comparable and consistent data products for stakeholders."

*Multibeam echosounder best practice team leader, **Vanessa Lucieer,** Institute for Marine and Antarctic Studies,*

Effective surveys for marine industries

"Efficient and trustworthy biodiversity sampling is important for marine industries, but ship time, equipment and expert services can be expensive and limit survey times, especially in deeper offshore waters. In 2020, the Hub's best practices were used to design and conduct a cost-effective stereo-BRUV survey of deeper water (100–180 m) fish communities in the Pilbara area for Woodside Energy Ltd. The survey was led by Guardian Geomatics with assistance from Advisian and The University of Western Australia. In a short timeframe the team collected sufficient samples to provide robust population estimates and characterise the fish community across the study area."

*Baited remote underwater stereo-video best practice team leader **Tim Langlois,** and **Anita Giraldo,** The University of Western Australia*

Sustained use is the biggest challenge

"One of the key challenges in developing best practice guidelines for marine sampling and monitoring is also one of the greatest rewards. Bringing together a national suite of experts to form a working group can be challenging, but when you get that right great things can be achieved. The biggest challenge though lies in maintaining the uptake and adoption of best practices so that monitoring change in our marine environment can actually be achieved on a national scale, and have lasting impact. This means being persistent and consistent in the application of our best practices, and leading by example."

*Towed imagery best practice team leader, **Andrew Carroll,** Geoscience Australia*

Urging regulators to get onboard

"Best practices will allow us to build bigger datasets and longer time series because field work done by different organisations in different places at different times will produce outputs that are nationally consistent. A significant step would be for regulators to require the use of best practices in environmental impact assessments and operational monitoring programs. To have the research and development sector, government agencies, consultants and marine industries working together in this way would be a great outcome for Australia's blue economy."

***Tim Moltmann,** former director of the Integrated Marine Observing System, former chair of the National Marine Science Committee, and present chair of the NESP Marine and Coastal Hub Steering Committee*

FURTHER INFORMATION
rachel.przelslawski@dpi.nsw.gov.au
Field manuals for marine sampling to monitor Australian waters

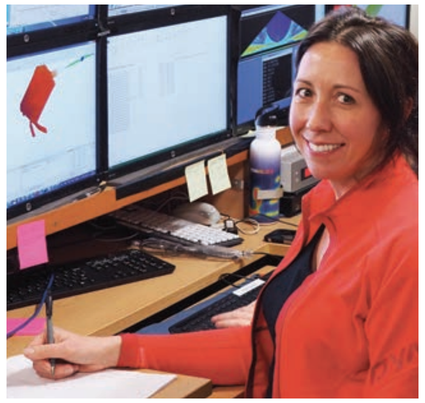
BELOW LEFT TO RIGHT:

Vanessa Lucieer on RV *Tangaroa*. Image: NIWA RV *Tangaroa.*

Tim Langlois and Anthea Donovan sampling at Ningaloo Marine Park. Image: Brooke Gibbons

Andrew Carroll with the deep-tow camera beside RV *Investigator*. Image: Rachel Nanson, Geoscience Australia/ CSIRO Marine National Facility

Tim Moltmann. Image: Integrated Marine Observing System



7 People

Justin Hulls of the Institute for Marine and Antarctic Studies on the *Bluefin* at Beauty Point, Tasmania.

Hub participants

Administration

Louise Bell
Graphic Designer

Bryony Bennett
Communication Manager

Emma Flukes
Data Manager

Sarah Gracie
Senior Executive Officer

Paul Hedge
Deputy Director, Knowledge Broker

Annabel Ozimec
Communication Support Officer

Vicki Randell
Executive Officer

June Wright
Administration Officer

Hub partners

Australian Institute of Marine Science

Prue Addison
Ken Anthony
Mark Case
Martial Depczynski
Luciana Ferreira
Rebecca Fisher
James Gilmour
Ronen Galaiduk
Michelle Heupel
Andrew Heyward
Eric Lawrey
Mark Meekan
Karen Miller
Camille Mellin
Miles Parsons
Marji Puotinen
Ben Radford
Claire Streten
Hugh Sweatman
Michele Thums
Vinay Udyawer
Muhammad Abdul Wahab
Mary Wakeford
Terry Walshe

Charles Darwin University

Kate Buckley
Hamish Campbell
Christy Davies
Peter Kyne
Viv Tulloch-McShane

CSIRO

Sharon Appleyard
Franzis Althaus
Russ Babcock
Simon Barry
Nic Bax
Cindy Bessey
Russell Bradford
Mark Bravington
Barry Bruce
Norm Campbell
Simon Collings
Jeff Dambacher
Carlie Devine
Floriaan Devloo-Delva
Anthea Donovan
Ryan Downie
Mike Dunlop
Piers Dunstan
Stuart Edwards
Karen Evans
Pierre Feutry
Mibu Fischer
Karl Forcey
Scott Foster
Michael Fuller
Russell Gorddard
Mark Green
Peter Grewe
Rasanthi Gunasekera
Denise Hardesty
Keith Hayes
Mick Haywood
Richard Hillary
Geoff Hosack
Cass Hunter
John Keesing
Rudy Kloser
Emma Lawrence
TJ Lawson
Tim Lynch
Vanessa Mann
Tara Martin
Nick Mortimer
Sean Pascoe
Toby Patterson
David Peel
Richard Pillans
Qamar Schuyler
Leah Soo
Mark Tonks
Judy Upston
Mat Vanderklift
Tonya van der Velde
Ingrid van Putten
Dave Watts
Will White
Chris Wilcox
Alan Williams
Skipton Woolley

Geoscience Australia

Brendan Brooke
Andrew Carroll
Nicholas Dando
Hanna Evans
Georgina Falster
Zhi Huang
Aero Leplastrier
Leo Lymburner
Rachel Nanson
Scott Nichol
Claire Phillips
Kim Picard
Alix Post
Rachel Przeslawski
Stephen Sagar
Justy Siwabessy
Michele Spinoccia
Medhavy Thankappan

Integrated Marine Observing System (IMOS)

Sebstien Mancini
Roger Proctor

Museums Victoria

Guadalupe Bribiesca-Contreras
Andrew Hugall
Robin Wilson
Tim O'Hara
Alexandra Weber

NSW Department of Planning, Industry and Environment

Peter Davies
Tim Ingleton
Michelle Linklater
Tim Pritchard
Michael Sutherland

NSW Department of Primary Industries

Faith Doyle
Chris Gallen
David Harasti
Roger Laird
Brett Louden
Jeff Murphy
Kylie Russell
Matt Taylor
Kate Thornborough
Joel Williams

University of Tasmania

Neville Barrett
Tyson Bessell
Christine Crawford
Lara Denis-Roy
Graham Edgar
Andrew Fischer
Bethany Green
Marcus Haward
Freddie Heather
Alex Hormann
Justin Hulls
Lainey James
Sarah Jennings
Craig Johnson
Alan Jordan
Valeria Komyakova

Cayne Layton
Scott Ling
Vanessa Lucieer
Jeremy Lyle
Jacquomo Monk
Vishnu Prahalad
Qurratu Ayunin Rohmana
Jeff Ross
Jemina Stuart-Smith
Rick Stuart-Smith
Darryn Sward
Emre Turak
Joanna Vince
Kathy Willis
Lincoln Wong
Jeffrey Wright

The University of Western Australia

Simon Allen
Charlotte Aston
Rachel Austin
Phil Bouchet
Michael Burton
Harri Davies
Jane Edgeloe
Brooke Gibbons
Fiona Gibson
Anita Giraldo Ospina
Violet Harrison-Day
Alex Hegarty
James Hehre
Renae Hovey
Gary Kendrick
Marit Kragt
Tim Langlois
Jessica Meeuwig
Matthew Navarro
Naima Rodriguez Lopez
Abbie Rogers
Elizabeth Sinclair
Claude Spencer
John Statton
Thomas Tothill

Project partners and collaborators

Andy Townsend Design

Andy Townsend

Anindilyakwa Land and Sea Rangers, Anindilyakwa Land Council

Katie Oxenham
Keith Lambert
Jeff Paul

Applied Archaeology International

David Guilfoyle
Genevieve Carey

Auckland University

Emma Carroll

Australian Antarctic Division

Names withheld according to privacy policy

Australian Department of Agriculture, Water and the Environment

Names withheld according to privacy policy

AH Photography

Andrew Halsall

British Antarctic Survey, UK

Jennifer Jackson

Burning Sheep Productions

Asher Flatt

Clean Ocean Foundation

Rebecca Banks
Claire Boucher
John Gemmill
Peter Smith

Current Environmental

Claire Charlton

Curtin University

Claire Charlton
Christine Erbe
Rebecca Wellard

Crow's Nest Media

Fraser Johnston
Andrew Terhell

Department of Agriculture and Fisheries, Queensland

Carla Wegscheidl

Department of Environment and Energy, ACT

Amanda Miller
Susan Powell

Department of Environment and Water, South Australia

Dirk Holman

Department of Environment, Land, Water and Planning, Victoria

Mandy Watson

Department of Primary Industries, Parks, Water and Environment, Tasmania

Rachael Alderman
Kris Carlyon
Sheryl Hamilton

Department of Primary Industries and Regional Development, Western Australia

Christopher Dowling
Anthony Hart
Mathew Hourston
Claire Smallwood
Gabby Mitsopoulos

DigsFish

Ben Diggles

Edith Cowan University

Ankje Frouws

Girringun Land and Sea Rangers

Cindy-lou Togo
Hayden Togo

Infotech Research

John Cumming

James Cook University

Katya Abrantes
Lisa Bostrom-Einarsson
Andrew Chin
Colin Creighton
Jacob Fries
Karin Gerhardt
Ian McLeod
Carlo Mattone
Jemma Purandare
Marcus Sheaves
Colin Simpfendorfer

Macquarie University

Robert Harcourt
Francisco Martinez Baena

Malak Malak Ranger Group, Northern Land Council

Theresa Lemon
Rob Lindsay
Travis Maloney
Aaron Shields
Amos Shields
Matthew Shields

Malgana Aboriginal Corporation (in support of the Malgana Land and Sea Ranger Program)

Richard Cross
Alex Dodd
Marika McNeair
Nykita McNeair
Sean McNeair
Cody Oakley
Patricia Oakley
Nicholas Pedrocchi

Socialising group of Southern Right Whales near Esperance, WA, during the annual aerial population survey. Image: Joshua Smith

Vale John Bannister and Colin Creighton

JOHN BANNISTER 1937–2018

John Bannister began life in London and studied zoology at Oxford University. His whale research took him to South Georgia and South Africa, and to Perth, Australia, where he worked for CSIRO and the Western Australian Museum. He studied Sperm Whale assessment and biology, Southern Right Whales, Humpback Whales and Blue Whales. He became Curator of Mammals at the museum and ultimately a highly successful Director. John initiated the project to assess the status of Southern Right Whales off southern Australia, based on annual aerial surveys beginning in 1976. He continued this work as an honorary associate after his retirement in 1991. This included leading the aerial surveys through the Marine Biodiversity Hub. These long-term monitoring surveys generated one of the most valuable long-term whale data sets in the world. John represented the United Kingdom and Australia on the International Whaling Commission's Scientific Committee and also chaired the committee. He was a Scientific Fellow of the Zoological Society of London and a Fellow of the Linnaean Society.

John was a lover of books and collected first editions of Arthur Ransome's Swallows and Amazons. Shortly before his death, he commissioned the building of the *Grizzled Skipper*, named after a favourite European butterfly, but based on the boat from Swallows and Amazons. The boat was handcrafted in Tasmania from Huon Pine.

Extracted from* Marine Mammal Science *2020; 36:1074-1077 Society for Marine Mammology

Saltmarsh in northern Tasmania is a nursery for many species, including commercial fishes. Images: Vishnu Prahalad

COLIN CREIGHTON AM, 1959–2020

Colin Creighton hailed from Grafton in New South Wales and persued studies in metallurgical engineering, natural resources and management. He was passionate about exploring efficient and sustainable land use practices and worked with farmers, foresters, fishers, conservationists, managers and policymakers to achieve more productive landscapes across Australia and its near neighbours. Based near Mackay, Queensland, for many years Colin was an adjunct principal research scientist for the Centre for Tropical Water and Aquatic Research at James Cook University. He was the inaugural President of the Global Water partnership, and led the first National Land and Water Resources Audit for Land and Water Australia, completed in 2002. He was also the inaugural Director of the CSIRO Water for a Healthy Country Flagship. His work with the Fisheries Research and Development Corporation and the Marine Biodiversity Hub included studying the impacts of climate change on coastal ecologies and fisheries, and the benefits of restoring coastal habitats.

In 2018 Colin was named a Member of the Order of Australia for his significant service to environmental science and natural resource management, particularly to marine biodiversity, coastal ecology, fisheries and sustainable agriculture.

Extracted from* FISH *Vol 28 2. Fisheries Research and Development Corporation.

MIRG Australia
John Totterdell

Mosaic Environmental
Gina Lincoln

Murdoch University
David Morgan
Joshua Smith
Jeff Whitty

National Oceanic and Atmospheric Administration
TJ Moore
Jessica Redfern

Northern Territory Government
Diane Barton
Rachel Groom
Mark Grubert
Grant Johnson
Robbie Risk
Thor Saunders
Alan Withers

Parks Australia
Names withheld according to privacy policy

South Australian Research and Development Institute
Paul Rogers

Sustain Nature Communications
Amrit Kendrick

The Nature Conservancy
Chris Gillies

Undalup Association Inc.
Shannon Clohessy
Zac Webb
Toni Webb
Wayne Webb

University of Queensland
Phoebe Stewart-Sinclair

University of St Andrews, UK
Emma Carroll
Phil Hammond

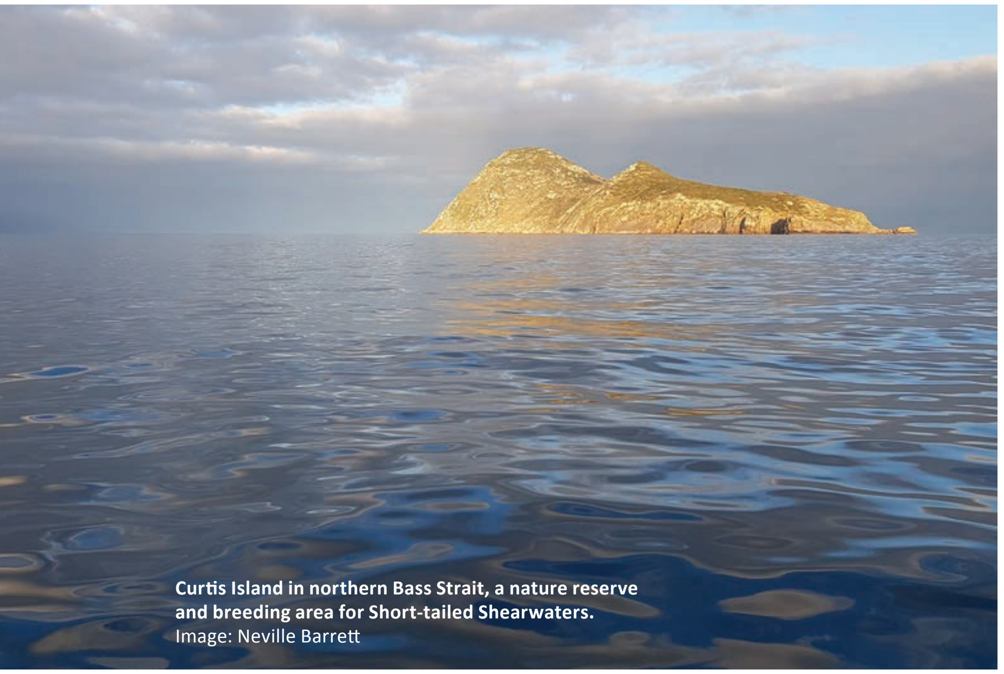
University of Sydney (via IMOS AUV Facility)
David Henderson
Christian Lees
Jorja Martin
Oscar Pizarro
Christian Reeks
Lachlan Toohey
George Wakeham
Stefan Williams

Western Australian Museum
John Bannister
Diana Jones
Kenny Travouillon

Wudikupildiyerr Ranger Group, Northern Land Council
Camillus Perry

Yirrgandji Land and Sea Rangers
Tarquin Singleton

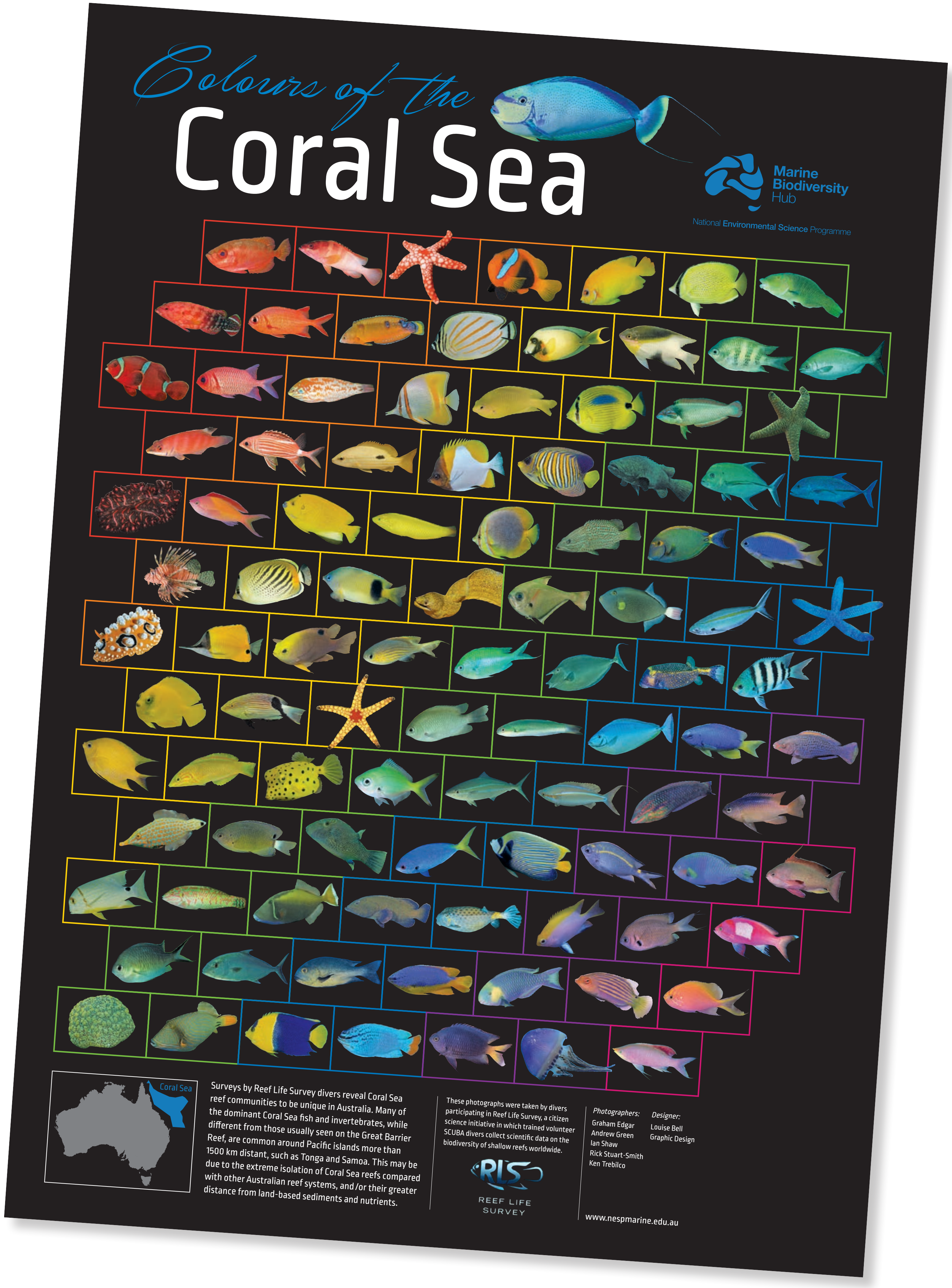
Yuku Baja Muliku Rangers
Michael Hale



Curtis Island in northern Bass Strait, a nature reserve and breeding area for Short-tailed Shearwaters.
Image: Neville Barrett

Additional organisations involved in preparing and reviewing the *Field manuals for marine sampling*

Acoustic Imaging
Aquaculture Science, United Kingdom
Australian Maritime Safety Authority
Australian Ocean Data Network
California Department of Fish and Wildlife
Centre for Environment, Fisheries and Aquaculture Science
Deakin University
Department of Conservation, New Zealand
EGS, International
Flinders University
FrontierSI
Fugro, International
GreyBits
Institut de Recherche pour le Developpement, France
iXblue, International
Japan Agency for Marine-Earth Science and Technology
Land Information New Zealand
Massey University, New Zealand
National Institute of Water and Atmospheric Research, New Zealand
National Oceanic and Space Administration, United States
Parks Victoria
Queensland Department of Environmental and Heritage Protection
Maritime Safety Queensland
Royal Australian Navy Australian Hydrographic Office
RPS, International
São Paulo State University, Brazil
Silliman University, Philippines
South African Institute for Spanish Research Council Aquatic Biodiversity
University of Melbourne
University of New South Wales
University of Southampton, United Kingdom
Victorian Department of Infrastructure and Regional Development
Western Australia Department of Biodiversity
Western Australia Department of Transport
Zoological Society of London, United Kingdom



Male Leafy Seadragon (*Phycodurus eques*) with eggs.
Rapid Bay, South Australia. Image: Tom Bridge, Tethys Images

CONTACT

Director
NESP Marine Biodiversity Hub
Alan Jordan
alan.jordan@utas.edu.au
www.nespmarine.edu.au

The NESP Marine Biodiversity Hub is funded by the Australian Government's National Environmental Science Program. Our goal is to assist decision-makers to understand, manage and conserve Australia's environment by funding world-class biodiversity science.