IMOS

Integrated **Marine Observing** System

IMOS Five Year Plan (2022-27)

6 September 2021

NCRIS National Research Infrastructure for Australia
An Australian Government Initiative

Australia's Integrated Marine Observing System (IMOS) is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent.

UNIVERSITY of TASMANIA

Contents

Vision for Action	1
IMOS Missions 2021-2030	1
Current Context	2
Delivering Benefit	3
The IMOS Program	7
Our Capability	9
Proposed Portfolio	11
Emerging Priorities	15
Data Delivery	17

Acknowledgement to Country

IMOS acknowledges with deep respect the Traditional Custodians and Elders of the land and sea on which we work and observe, and recognise their unique connection to land and sea.

We pay our respects to Aboriginal and Torres Strait Islander peoples past, present and future.

IMOS especially honours Traditional Owners as Australia's first marine scientists and carers of country, and we pay tribute to Traditional Ecological Knowledge, wisdom, and Indigenous perspectives passed from generation to generation, and successfully applied to sustainable environmental management over thousands of years.

IMOS
Integrated **Marine Observing** System

Integrated Marine Observing System (IMOS)
Private Bag 110
Hobart, TAS, Australia, 7001

Phone: (03) 6226 7549
Email: imos@imos.org.au
www.imos.org.au

Vision for Action

Australia's Integrated Marine Observing System (IMOS) was established in 2006 and is a joint venture between seven of Australia's top marine research institutes. It is a national infrastructure capability enabled by the National Collaborative Research Infrastructure Strategy (NCRIS), to provide sustained observation and measurement of Australia's oceans for the sustainable use and management of our marine estate. IMOS observations span from the open ocean to the coast and range from physical, biological, chemical and atmospheric measures. With a network that stretches from the Southern Ocean to the tropics, these data are integral to understanding the state of our marine ecosystems, weather and climate. IMOS engages with stakeholders and end-users to provide centralised and timely data delivery to serve national needs and is one of the world's most comprehensive and successful ocean observing systems.

Based on more than a decade of providing high-quality data to better understand Australia's vast marine estate, IMOS has a singular goal:

> *To deliver benefits to Australia by undertaking systematic, sustained and scientifically-robust observations of our vast and valuable marine estate.*

To realise this goal, IMOS has developed a Decadal Strategy to ensure societal benefit for Australia through maintaining and enhancing ocean observations designed to address fundamental questions and challenges facing our marine estate.

This Five Year Plan describes the elements of the IMOS program that will help us achieve and deliver the Missions and objectives outlined in our Decadal Strategy. Grounded in the new Decadal Strategy, IMOS will continue to evolve the program to have a user-driven focus and strong commitment to delivering societal benefit. IMOS' future observing will deliver observations and measurements to support industry, management, research and training activities to achieve real-world benefits for Australia and our regional neighbours.

Five dedicated Missions will help IMOS focus our efforts to deliver the best program possible and maintain a world-class ocean observing system.

IMOS Missions 2021-2030:

Through strategic coordination, collaboration and best practise data stewardship and delivery IMOS will:

- Provide data and knowledge to improve decision-making and support operational needs, safety and efficiency of marine industries and organisations, including weather forecasting and prediction services
- Provide an increased understanding of the environmental, economic, social and cultural impacts of and resilience to climate change and extreme events
- Enable improved understanding of conditions, species and habitats to support management and protection of our precious marine estate
- Support research, training and education, and facilitate innovative approaches to provide future ocean-monitoring capabilities for industry, science and management
- Engage at local, national, regional and international scales to ensure our capacity and capability is leveraged for greatest impact

Current Context

As one of the 12 foundation NCRIS capabilities IMOS has a strong track record of delivery and is widely recognised as a high calibre national research infrastructure. IMOS acts as a vehicle for national and international collaboration and data exchange through our partners, associate participants, collaborators, end-users and stakeholders.

The IMOS program has grown to include 12 Facilities (Figure 1) and over 50 sub-Facilities that deliver sustained observing of Australia's marine estate from the open ocean to the coast. Collected observations include physical, biological, biogeochemical and atmospheric measurements to help understand the state, trends and future conditions of our marine estate, weather and climate. Administered by 11 operating institutions, the IMOS portfolio constitutes an unprecedented capability for marine observing in Australia. Strategic partnerships and integration of IMOS into national initiatives such as the National Environmental Science Program and the Blue Economy Cooperative Research Centre ensure IMOS is positioned to contribute to an array of projects, products and outputs. As the IMOS program continues to evolve to be more user-driven and meet the needs of research, industry and other end-user communities, our relationships and partnerships will also grow and evolve.

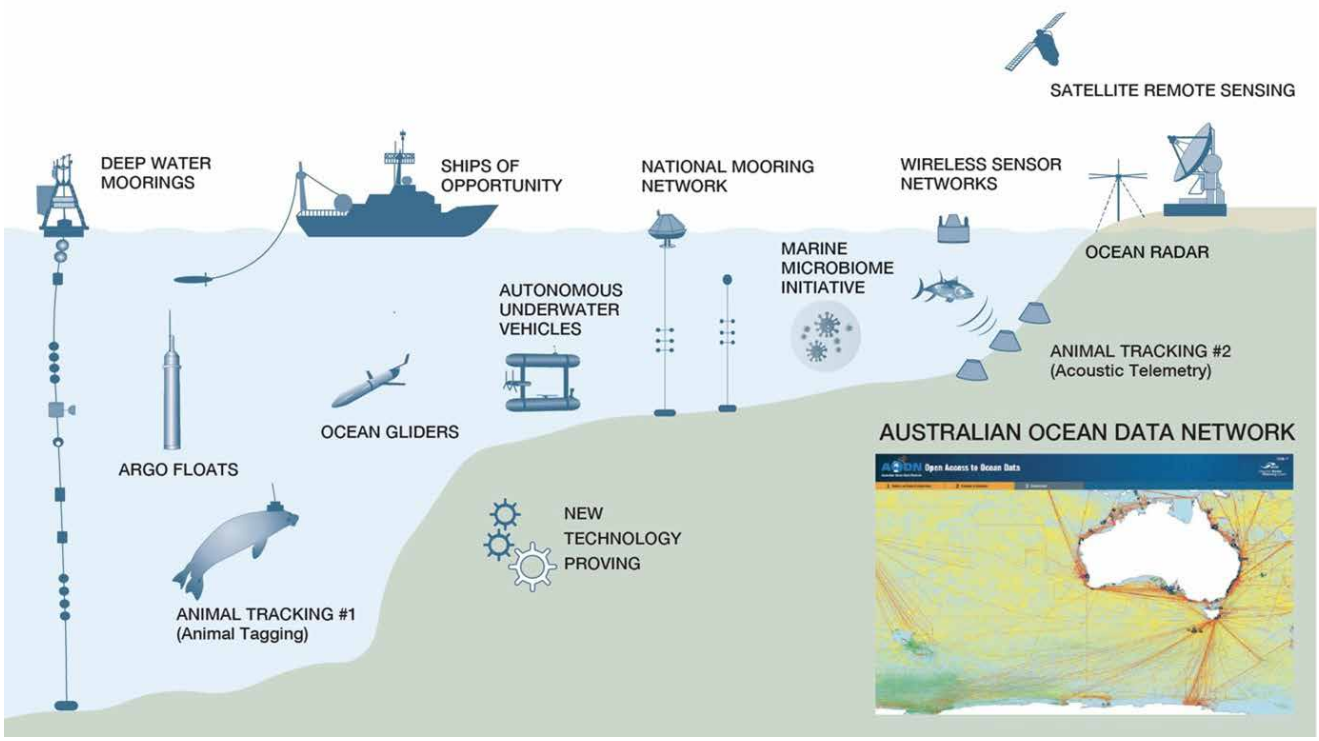


Figure 1. IMOS Facilities operating in the 2018-2022 period.

The science direction of IMOS is driven by a range of mechanisms including the National Marine Science Plan, the National Climate Science Strategy, Global Ocean Observing System 2030 Strategy, the United Nations Decade of Ocean Science for Sustainable Development 2021–2030 and national government priorities. Input from the IMOS regional Nodes and our Scientific and Technical Advisory Committee (STAC) also play a fundamental role in shaping IMOS. Jurisdictionally-based Nodes contribute to an understanding of the issues, priorities and problems at a regional level. Through communication and collaboration IMOS is able to compile a perspective that scales up regional needs into a national capability to create broad benefit. Current IMOS Nodes include a Bluewater and Climate Node and five jurisdictional Nodes (QLD, NSW, SA, Vic, WA). Priorities for the Northern Territory are currently captured via input into the QLD and WA Nodes, and a Tasmanian Node is in development. The Nodes also create a conduit for IMOS to communicate more broadly within regional communities. This linkage allows regional users to provide input to IMOS and also be informed about IMOS directions, outcomes, plans and opportunities.

IMOS operations are critically important in meeting the data needs of communities, industries, stakeholders and end-users to produce societal benefits for Australia and our region. Ocean observations and measurements support an array of societal benefits including safety, operational efficiency, helping to identify weather patterns, understanding water quality conditions and tracking animal movements. All of these elements contribute to the jobs, recreation, health and wellbeing of Australians through an improved understanding of our ocean environment.

IMOS and its partners play a pivotal role in meeting Australia's needs for marine data, meet geographic and ecological coverage requirements and provide an effective national integrated marine observing system. To achieve our objectives and meet the needs of Australia's diverse marine science stakeholder community, IMOS adheres to four Key Performance Indicators (KPI):

1. Deploy and recover equipment;
2. Make the data available;
3. Ensure uptake and use of the data;
4. Ensure the relevance and impact of science outputs.

A key element of IMOS' capability and capacity to meet our KPIs is the Australian Ocean Data Network (AODN). The AODN is tasked with managing and delivering data collected by IMOS Facilities. The AODN publishes IMOS data under the FAIR principles (Findable, Accessible, Interoperable, Reusable), making all of our data openly available to the public. Dedicated data management and delivery of IMOS data via the AODN Portal helps ensure IMOS can meet KPIs 2 and 3. This facilitation of uptake and use of IMOS data provides the opportunity for IMOS observations to be used in a range of publications, reports, products and other outputs, as well as integration into training opportunities, management and policy decisions, and use in maritime and industry operations.

Delivering Benefit

Australia's research infrastructure helps ensure we stay at the forefront of science, research and innovation. As noted in the Commonwealth Research Infrastructure Investment Plan, a modern and world-class research infrastructure will help drive advances in technology and knowledge that boost productivity, create jobs and deliver economic growth.

To ensure we achieve this, the IMOS Office has adopted an Impact Framework. This Framework helps measure and explain the societal, scientific, technological, economic and community-based, and training and education benefits a sustained ocean observing system can deliver to Australia (Figure 2). This Framework will help map out a strategic 'pathway to impact' to ensure that as a research infrastructure delivering sustained ocean observations, IMOS can deliver on these critically important areas of benefit.

Observing the Impact of IMOS

As a research infrastructure IMOS delivers high quality marine and climate data to Australia's scientists, students, industries and other stakeholders for their use in research and operational activities. IMOS data is taken up and used thousands of times, creating impact and benefits at local, national and global scales. IMOS measures impact in two ways: through our **societal benefit** and through our more proximate **research infrastructure impact**.

IMOS Societal Benefit

Australia has an expansive marine estate, which influences many aspects of our social, cultural and economic lives, and the environment in which we live. The importance of our marine estate is reflected in the range of areas where it intersects with areas of societal benefit. IMOS has identified five areas of societal benefit where our observations and data can produce value for Australia.

Coastal populations

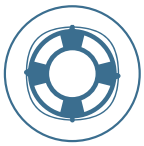
Infrastructure • Industry • Populations • Tourism • Human health

Food security

Fishing • Aquaculture • Recreational fishing • Agriculture

Energy security

Oil and gas industry • Renewable energy: terrestrial and ocean



Marine sovereignty, safety & security

Ports and shipping • Indigenous Australians and sea country • Border security and defence • Search and rescue • Regional security and aid

Biodiversity conservation & management

Threatened species • Monitoring & assessment • Environmental obligations • Biosecurity • Marine Protected Areas

Research Infrastructure Impact

Scientific

Be a national and world-leading research infrastructure and an enabling facility to support science excellence.

Technology and Innovation

Provide high quality scientific data and associated services, to underpin and enable innovation.

Training and Education

Promote educational outreach and knowledge transfer to support the next generation of marine and climate scientists.

Economic and Community

Support regional, national and international communities, industries and clusters of scientific excellence.

Social

Promote and support social responsibility within and beyond Australia's marine observing system.

Figure 2. Descriptions of IMOS areas of societal benefit and research infrastructure impact that are currently measured and tracked via collection of associated metrics and case studies.

Societal Benefit

Alongside the omnipresent global, regional, national and local threats of climate change, geopolitical drivers are increasing pressure on Australia's marine estate, and its climate and weather systems. Australia's maritime sovereignty, security, and safety; our energy security; our large coastal populations; our food security; and the conservation of our unique biodiversity, are all vulnerable to the pressures, impacts, and state of the ocean and its related climate and weather (Figure 2).[1] IMOS will measure how ocean observations relate to and are applied to helping support social and cultural aspects related to our marine estate through our areas of societal benefit and engagement activities. Measuring our progress against the needs of the community reinforces our user-driven approach and capacity to create benefit.

IMOS strategically plans to deliver research outcomes that support a whole-of-system approach to the challenges facing our marine estate and address areas of societal benefit. The five societal benefit areas are intended to express what a comprehensive and sustained national ocean observation capability can deliver to society while offering thematic flexibility to adjust to inevitable changes in government portfolios and policies.

Ultimately, IMOS must demonstrate and communicate its impact across broad societal areas. We can now track the pathway to impact of IMOS activities to better articulate the way our research infrastructure contributes to policy. By recording outputs of sub-Facilities, we can track use from data download to research output, through to policy-related literature and actions. We can also track project outputs to delivery against key policies and strategies by government, and then describe the ultimate impact this will have. The flexibility of the Impact Framework means that we can articulate our benefit across policies, portfolios, themes and regions. Through combining analyses of other areas of output through case studies, we can evaluate and measure the societal benefit of our program and make operational changes to ensure we maximise our impact.

Analysis of the application of IMOS data to the five societal benefit themes reveal differences amongst sub-Facilities with some having particular areas of societal benefit where they are more applicable than others, which is to be expected. However, scores are consistently low in the area of Energy Security. While it is acknowledged that IMOS cannot necessarily fulfil every niche, this lack of applicability highlights an area where IMOS has not traced the use of research by the energy industry, or currently isn't optimised to contribute heavily and there is an opportunity to do more. As new areas of the IMOS program mature (e.g. surface wind and waves measurements) they are likely to attract greater use by and relevance to the energy sector.

Research Infrastructure Impact

Scientific

The IMOS Impact Framework has a series of measures that highlight our role as a national and world-leading research infrastructure and an enabling facility to support scientific excellence. We record the collaborations involved in the development of peer-reviewed publications, as well as the collaborations involved in the many projects and partnerships that take up and use IMOS data. These collaborations often represent regional, national and global research priorities, and we recognise that by aligning prioritised research needs with our observational capacity helps ensure that we have robust pathways to impact.

Technology and Innovation

IMOS addresses technology and innovation through two main mechanisms. Our New Technology Proving Facility provides a platform for trialling and integrating new technologies and methodologies into ocean observing. In conjunction with technological advances, the AODN delivers data to underpin advances and innovation, including development of products and web apps by researchers and businesses.

IMOS strives to provide high-quality scientific data and associated products and services, to underpin and enable innovation. The AODN translates our many different types of observations into accessible data streams. The technical foundation of the AODN is now being leveraged to ensure even more stakeholders and end-users are able to access data to develop metocean models and benefit from data products.

As we move into the next planning phase, the uptake and use of IMOS data into models and products will be a priority. We will seek to encourage use of our data to form innovative products that benefit a broad range of end-users. We will measure and track the uptake and use of sub-Facility data into models and products, and work to articulate the uses of those models and products to track and capture benefit.

[1] Adapted from National Marine Science Plan (2015-2025): Marine Science for Australia's Blue Economy (2015).

Economic and Community

IMOS aims to support regional, national and international communities, industries, government and clusters of scientific excellence. The direct investment IMOS makes into sub-Facilities, and the collaborative support provided by the Nodes, reflect more proximate impacts of IMOS as a national research infrastructure. To ensure we deliver benefits to industry and across scales, IMOS will emphasise the need for partnerships and collaborations with industries, non-government organisations (NGOs), Traditional Owners, and regional, national and international communities to ensure that the benefits derived from IMOS are dispersed across all scales.

Training and Educational

The National Marine Science Plan (2015) calls for a workforce of world-class marine scientists equipped with strong quantitative skills, in tune with industry and government priorities, and working in inter- and transdisciplinary teams. As a national research infrastructure, IMOS will contribute to this effort by promoting educational outreach and knowledge transfer to support the next generation of job-ready marine and climate scientists. In addition, IMOS supports a range of marine technical experts. The training and retention of these highly skilled individuals is imperative to delivering an ocean observing program of this scale.

IMOS will achieve this by ensuring data is open, accessible and publicised so that students and early career researchers across the country have equal access to every observation we have collected under FAIR data principles. We will encourage the community to be ambassadors for our data and ensure that our platforms can deliver model-ready data to students and their mentors and teachers.

Measuring Success

To successfully fulfil the Missions of the IMOS Decadal Strategy we will apply the elements included in this Five Year Plan to:

- Increase our societal benefit promoting the use of our observations to align with regional, national or international priorities and strategies, therefore ensuring their relevance and impact.
- Increase our scientific impact by underpinning research outputs that maintain and exceed the above-average level of scientific excellence of our peer-reviewed publications and reports.
- Advance the provision of high-quality data and associated technological services, such as products, to ensure our observations are used in innovative and impactful ways.
- Increase our economic and community-based impact by enabling and integrating the observational needs of industries, regional communities, Traditional Owners, and other communities.
- Continue our educational outreach and knowledge transfer to support the next generation of skilled technicians and marine and climate scientists.

As part of measuring success we will collect, assess and analyse indicators of the use and users of IMOS observations and related research in and by:

- fisheries, aquaculture, tourism, ports, oil and gas, and renewable energy initiatives and coastal resource managers
- organisations such as the Bureau of Meteorology and the Department of Defence
- State and Commonwealth government agencies
- various policy documents
- state-of-the-art climate change research, modelling and forecasting
- biodiversity conservation and management, and food security
- university-based training and projects
- apps and other innovative products and technologies
- stakeholder and end-user engagement within local, national, regional and international institutions and partnerships.

The IMOS Program

In the IMOS 2030 Strategy the program has been framed around several fundamental elements: ***Need, Capability, Amplify*** and ***Impact***. There is an ongoing and increasing need for ocean observing within and beyond Australia which is evident in national and international plans and policies. Numerous plans and strategies emphasise or imply the need for sustained ocean observing including:

Global Plans and Strategies

- Global Ocean Observing System 2030 Strategy
- Global Ocean Observing System Framework for Ocean Observing
- GEO Blue Planet
- Southern Ocean Observing System
- United Nations Decade of Ocean Science for Sustainable Development 2021–2030
- United Nations Sustainable Development Goals
- Intergovernmental Panel for Climate Change Reports

National Plans and Strategies

- National Innovation and Science Agenda
- 2016 National Research Infrastructure Roadmap
- 2018 Research Infrastructure Investment Plan
- National Science and Research Priorities (Food, Soil & Water, Transport, Energy, Resources, Environmental Change)
- National Marine Science Plan
- National Climate Science Strategy
- Reef 2050 Long-Term Sustainability Plan
- Australian Marine Parks Management Plans
- Defence White Paper
- National Fisheries & Aquaculture RD&E Plan
- Australia's Strategy for Nature 2018-2030
- Foreign Policy White Paper
- Developing Northern Australia White Paper
- Australian Civil Space Strategy 2019-2028
- Australian Antarctic Science Strategic Plan 2020
- Threat abatement plan for the impacts of marine debris on the vertebrate wildlife of Australia's coasts and oceans 2018
- MarinePestPlan 2018-2023: National Strategic Plan for Marine Pest Biosecurity

Regional Plans and Strategies

- Northern Territory Marine Science End User Needs Analysis
- NSW Marine Estate Management Strategy
- Queensland Coastal Management Plan
- South Australian Marine Planning Framework for South Australia
- Tasmanian State Coastal Strategy
- Victorian Marine and Coastal Strategy
- Western Australia Blueprint for Marine Science 2050

Using these strategies, plans and other drivers, IMOS and its partners fill a fundamental role in delivering ocean observations at a scale that meets the needs of the nation. The drivers for observations change through time, and therefore the observations and measurements required to fill these needs also change. The strong relationships IMOS has with stakeholders, end-users and industry help ensure that we can adapt and evolve to meet their needs.

The Power of Partnership

IMOS functions as a national-scale partnership which is one of the major strengths of the program. The scale and scope of the IMOS program provides the opportunity to operate in ways not feasible in other marine programs. In the period of 2022-2027 IMOS will be undertaking a transformational journey where we expand our portfolio and collaborations, work strategically as a collective and ultimately produce integrative outputs that can help contribute to solving ongoing and emerging issues in the marine environment.

IMOS requires strong collaborations to deliver the required outputs to help understand and sustainably manage our oceans. Our community is one of our greatest strengths. IMOS has a long and strong track record of collaboration and connectivity. Analysis of IMOS outputs reveals high connectivity (e.g. shared authors or data) among Facilities (Figure 3). This connectivity is indicative of the IMOS culture of sharing capability and data. As we enter the next five years of IMOS, these relationships and dependencies will be more important than ever as we work to address increasingly complex problems facing our nation and region.

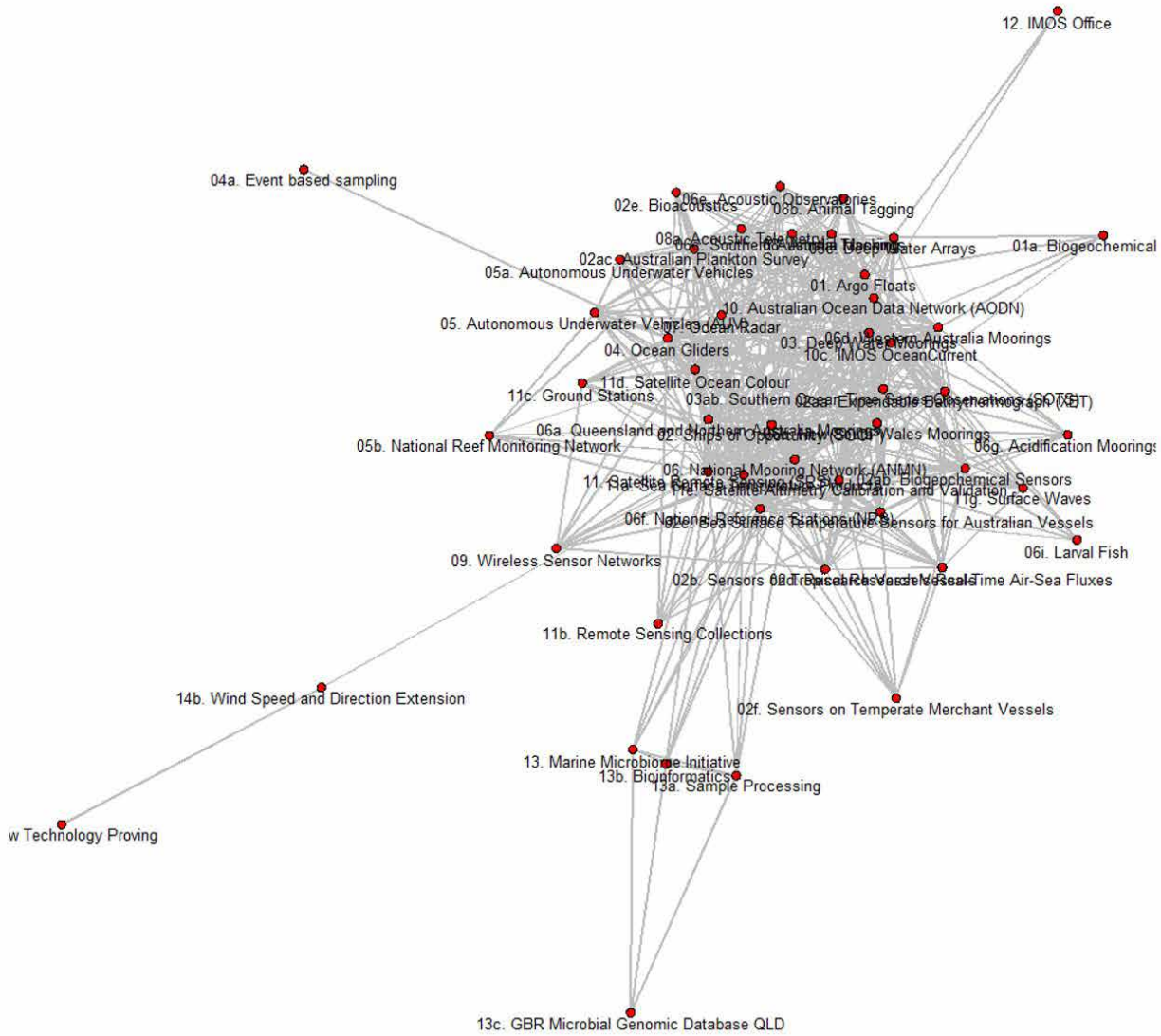


Figure 3. Network analysis revealing level of connection among outputs produced by IMOS Facilities. Outlying Facilities (e.g. New Technology Proving) are primarily Facilities with shorter operational duration than others, or those with specific administrative functions (e.g. IMOS Office).

As we look forward into the next five years we need to consider how we can enhance our community and partnerships by joining with new individuals and new topics. In the period from 2022-2027 IMOS will work more closely with citizen science and Traditional Owner groups. Building new partnerships, will expand our knowledge base, data streams, community linkages and relevance. Our oceans are important to all Australians and we need to engage broadly to capture their interests, skills, knowledge and help fulfil their needs.

IMOS will continue to engage in a range of strategic partnerships that are important to increasing use and uptake of IMOS data, as well as continuing our valuable relationships with other national-scale research infrastructures and programs (e.g. NCRIS capabilities, the Marine National Facility, Australian Research Council and Cooperative Research Centres). Links to the NESP 2.0 Climate Systems and Marine and Coastal Hubs will help maintain the relevance of our observations to these programs. The location of IMOS infrastructure and Facility operations in the Southern Ocean and Antarctica also make IMOS a natural partner in the Australian Antarctic Program Partnership and contributor to the Commission for the Conservation of Antarctic Marine Living Resources. Beyond Australia IMOS continues to function as a Global Regional Alliance for the Global Ocean Observing System. In this arena we play a key leadership role for the Indo-Pacific region as well as within the global network. IMOS is also a voluntary contribution to the United Nations Ocean Decade Sustainable Development Goal 14 (Life Under Water). Our data and observations will continue and increase as we play a broader role in this and other UN initiatives. The ability for IMOS to link into these programs is a testament to the quality and value of the data we collect for research and operational activities in Australia and beyond.

Our Capability

Here we summarise the elements of the 2022-2027 IMOS program. The proposed portfolio considers current capability and delivery of existing Facilities, realised and potential for impact from existing Facilities, and a planning for impact approach to ensure current and future IMOS infrastructure is designed to create societal benefit, within existing funding constraints. A review of the current program, identifying existing gaps and exploring emerging priorities has informed the development of this plan (Figure 4). *While the forward funding is not yet known and this plan is not costed, decisions have been made that work to meet the proposed direction of the program. It is important to note that delivery of the full suite of priority ocean observations will still rely on other institutions providing capability and resources beyond the IMOS contribution.*

The broad nature of the IMOS portfolio ensures that data can be provided to understand our ocean systems at multiple spatial and temporal scales to address issues ranging from the open ocean to our coastal communities and ecosystems.

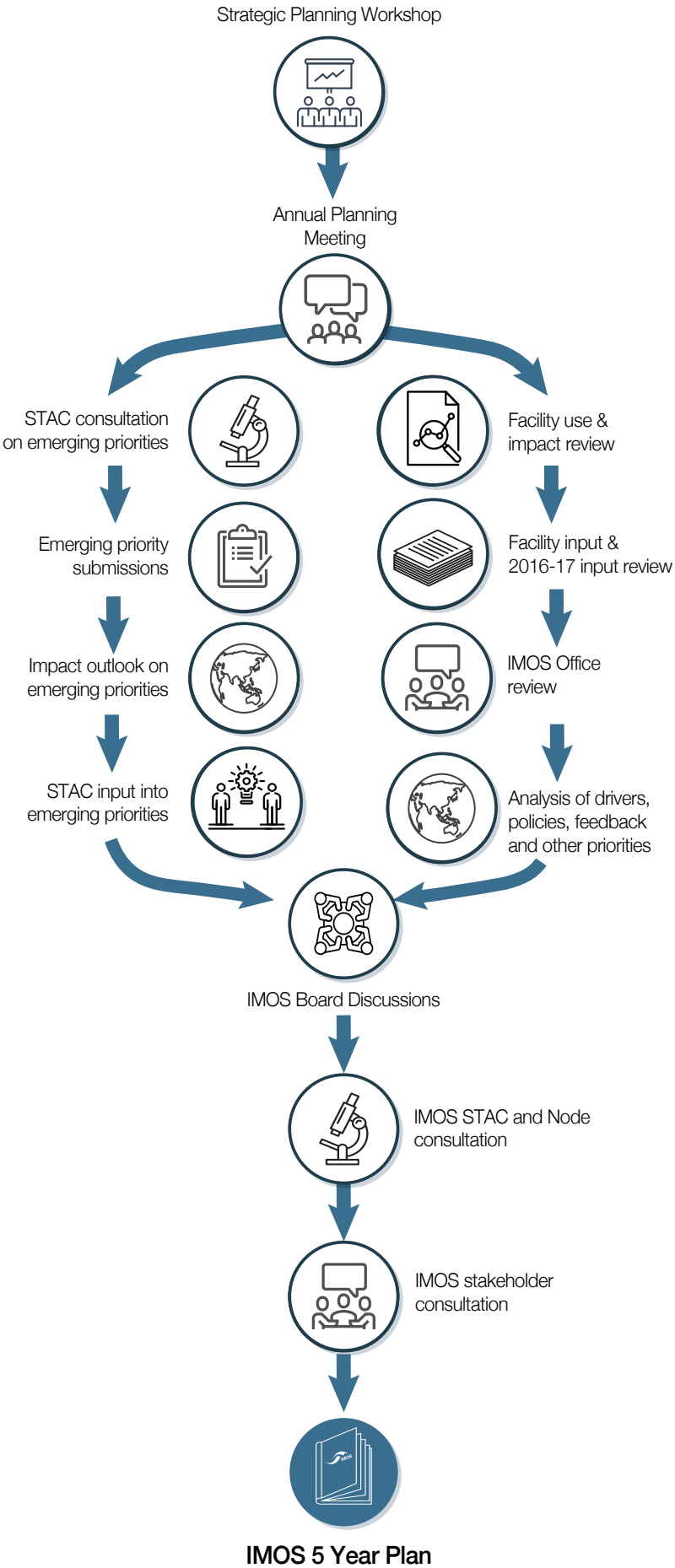


Figure 4: The broad process applied to develop this portfolio proposal.

Proposed Portfolio

The activities within IMOS are supported through the program level functions provided by the IMOS Office and Australian Ocean Data Network (AODN). These core elements are crucial to the strategic direction and day to day management and delivery of the IMOS program.

Argo

The Argo program provides ocean observations from floats equipped with a range of sensors and capabilities to help understand global heat and freshwater budgets, sea level change and underpin climate analyses. Through a coordinated program and plan for deployments, IMOS support contributes to the international program designed to understand global temperature and salinity structures. The core Argo program examines these parameters to 2000 m depth, while deep Argo extends this range to 6000 m to help observe critical ocean regions that can serve as heat sinks. Argo float capabilities also extend to collection of observations under sea ice and the collection of biogeochemical data (e.g. dissolved oxygen, pH, dissolved nitrate, chlorophyll) to help understand processes such as carbon pumping, uptake of CO_2, deoxygenation and acidification. These data inform several essential ocean variables and their rate of change. IMOS Argo continues to be a major contributor to understanding weather and climate and is an integral component of ocean observations and forecasting.

Satellite Remote Sensing

Satellites provide the capacity to make repetitive observations over vast areas of land or ocean. These observations are collected at a spatial scale difficult to match with other observing platforms and as such play a critical role in understanding the state and change of environments, especially relative to changing climate. Although largely confined to the surface layer, satellite remote sensing capability is improving as technology advances to include additional sensors and the ability to penetrate deeper into the water than previously. The IMOS Satellite Remote Sensing Facility works to help collect relevant satellite observations and make the resulting data more accessible, and easier for marine scientists to use. IMOS capability spans sea surface temperature, altimetry (ocean height), ocean colour, surface waves, and wind speed and direction.

In addition to producing data outputs for use in modelling, forecasting and research efforts, IMOS Satellite Remote Sensing also provides critical altimetry calibration and validation to support international missions like the US National Aeronautics and Space Administration (NASA) Surface Water Ocean topography (SWOT) mission launching in 2021. An IMOS support float in the Bass Strait is an integral component of the SWOT mission and the accuracy of the observations it produces. Through the Ocean Colour sub-Facility IMOS maintains ocean colour radiometry infrastructure at the Lucinda Jetty in north Queensland and Rottnest Island in Western Australia. The Rottnest Island site is being explored as a potential ocean colour calibration and validation site for the upcoming NASA Plankton, Aerosol, Cloud ocean Ecosystem (PACE) mission. These facilities are the only validation sites in the Southern Hemisphere and as such are critical for IMOS and others.

IMOS has also invested in wave measurement, and via the New Technology Proving process, now has wind speed and direction capability. Wave and wind measurements are increasingly important as we understand their influence on ocean circulation and coastal habitats. Remotely sensed wind and wave field measurements provide critical broadscale data for prospective marine industries. IMOS will continue to invest in these emerging areas. The IMOS Satellite Remote Sensing Facility contributes data to help better understand Australia's ocean environments and future advances suggest this capability will become more applicable in coastal environments over time. Continued IMOS investment in Satellite Remote Sensing will help inform modelling, forecasting and interpreting ocean conditions within and beyond Australia.

Ships of Opportunity

IMOS has been collecting observations from Ships of Opportunity since its inception. This Facility employs a range of research and commercial vessels to collect physical, chemical and biological data during regular vessel operations. Use of these volunteer vessels provides a platform for observations without the need for IMOS to charter vessels. Many vessels in the Facility conduct routine, repeated transits that provide sustained observations in a set location over time. Due to the wide range of vessels included in the Facility, and the range of sensors that can be fitted to

vessels, IMOS includes a number of sub-Facilities that focus on particular regions (e.g. temperate observing) or capabilities (e.g. biogeochemical observing). As such, a wide range of essential ocean variables are measured, and these are used to ground truth satellite observations, validate and inform models, and improve our understanding of conditions within and beyond Australian waters.

The Ships of Opportunity Facility provides observations for understanding ocean conditions and change, including providing data on boundary currents in remote regions. For example, measurement of carbon dioxide (CO_2) is important for national and international understanding of variability of the ocean carbon sink and potential implications of ocean acidification. Air-sea flux data are integral to climate modelling and projections and IMOS air-sea flux data are critical to global efforts. IMOS will continue to invest in Ships of Opportunity operations, but some consideration of the scale and composition of the program is needed to ensure efforts are optimised for needs and use by researchers, end-users, and stakeholders. This may include investigation of additional elements that help increase observing closer to the coast.

Deep Water Moorings

IMOS uses deep water mooring infrastructure to provide high-quality, high temporal resolution observations of physical, biogeochemical and chemical parameters over a large depth range. Deep water moorings provide continuous data on temporal patterns in conditions in real-time and delayed mode. The primary deep water mooring operated by IMOS is the Southern Ocean Time Series (SOTS) which includes three components: an air-sea flux mooring providing real-time meteorological and ocean condition data from the surface, a biogeochemical mooring measuring carbon cycles and marine productivity, and a deep ocean sediment trap. The SOTS mooring is one of the only air-sea flux installations in the Southern Hemisphere and the only one in the Southern Ocean. Given the important role of the Southern Ocean in absorbing CO_2 emissions and serving as a heat sink, there is a strong drive for IMOS to continue to monitor this region. IMOS is also a partner in an initiative by the US National Science Foundation led out of the Woods Hole Oceanographic Institute to re-instate the Indonesian Throughflow mooring to monitor movement of water from the western Pacific into the Indian Ocean.

National Mooring Network

IMOS' National Mooring Network is an expansive program that incorporates a range of capabilities. This Facility includes a collection of shelf mooring arrays deployed around the country and a network of National Reference Stations (NRS) that sample a range of variables, acidification moorings and wave buoys (Figure 5).

IMOS shelf moorings are deployed in Queensland, Northern Territory, Western Australia, South Australia, Victoria and New South Wales to collect data on oceanographic conditions and features such as boundary currents and upwelling, and ocean circulation and transport. This mooring array collects physical and biogeochemical data that are applied to ocean and coastal model development and validation and the time series serve as critical reference points for research. The need for fixed location, continuous data to support research, modelling and forecasting underpin the need for this capability.

National Reference Stations have created some of the longest running time-series of ocean observations to date. Observations in the NRS program include a suite of physical, biological and chemical variables ranging from temperature to plankton. The data collected at these sites is critical to understanding climate-related changes to ocean ecosystems and variability through time. This baseline data underpins modelling and helps define state and trends through time. The NRS activities also support other sampling efforts such as water sampling for marine microbes and marine plastics. IMOS currently supports seven NRS sites and due to their continual high relevance and importance they will remain an integral component of the IMOS program.

Ocean acidification moorings have been deployed in conjunction with the NRS system at two sites (Maria Island, Kangaroo Island) and a third mooring is deployed at Heron Island in the Great Barrier Reef. These specially designed moorings measure CO_2, which as described above, is critical to understanding ocean acidification. These locations enhance the Ships of Opportunity CO_2 data and feed into international research priorities and programs on ocean acidification. Data also help to build the resilience of fishing and aquaculture industries likely to be affected by increasing ocean acidification (e.g. oysters, rock lobster, prawns) through an improved understanding of the effect of variations in marine chemistry on target organisms, new knowledge about the drivers of this variability, and the development of tools which promote the evolution and implementation of mitigation strategies. There is a strong and ongoing need to understand the implications of climate change and ocean acidification.

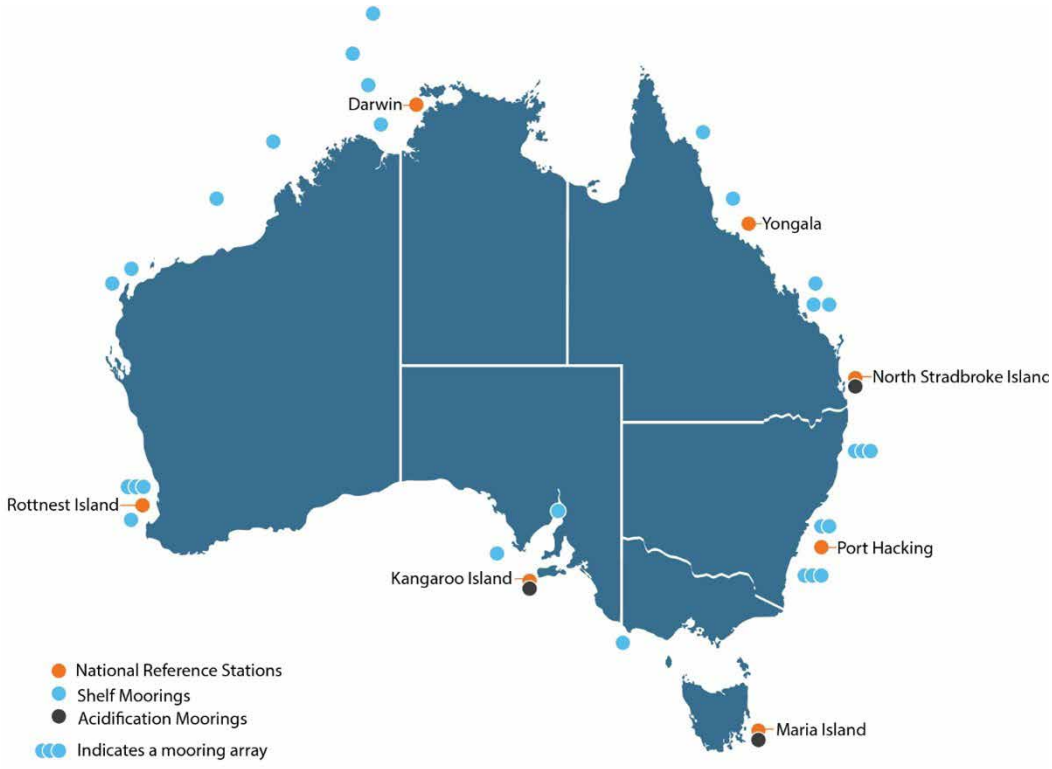


Figure 5: Locations of IMOS shelf moorings and National Reference Stations.

The final element of the National Mooring Network Facility is wave buoys which measure sea state, temperature and current conditions. These in situ observations enhance and validate satellite-based observations and help inform oceanographic modelling. Oceanographic models further inform ecosystem models by contributing contextual environmental data to model scenarios to create indirect benefit from IMOS oceanographic data. The relevance and importance of these observations for modelling and forecasting ocean conditions, including extreme storm events, in addition to direct application to maritime operations by industry, Defence and others highlights the importance of this capability within IMOS.

Autonomous Underwater Vehicles

The IMOS Autonomous Underwater Vehicle (AUV) Facility is comprised of several elements designed to better understand the condition and trends of benthic habitats in Australia. Through repeated sampling of key habitats, we have gained an understanding of how habitats are changing through time and whether environmental conditions are driving or can explain any observed changes.

IMOS has historically collected benthic imagery from a single vehicle operated on a national scale. However, in addition to IMOS efforts there are a growing number of institutions collecting benthic imagery using a range of methods. The collection and use of marine imagery is, therefore, a topic of national interest. Benthic imagery requires an individual to identify organisms and annotate the images, regardless of the method of collection. This labour-intensive process creates a backlog in the availability and use of benthic imagery. To help resolve this issue, IMOS has invested in an Understanding of Marine Imagery sub-Facility to establish a repository for benthic image annotations. This platform is designed to help facilitate image annotation, but more importantly, provides an open access repository of annotated images that can be used to create libraries to help train machine learning algorithms to automatically process benthic images and identification of organisms. The advent of automated image analysis will reduce the time and labour associated with assessing marine imagery and will increase the use and applicability of imagery collected within and beyond IMOS.

An additional sub-Facility within the AUV program is the National Reef Monitoring Network. This sub-Facility focuses on delivery of a database of observations collected through the Reef Life Survey citizen science program. IMOS supports delivery of a database to host these diver collected data and make them publicly available. The database comprises data on the size and abundance of reef-dwelling species collected via transect surveys. In addition, benthic imagery is collected in habitat quadrats. These data create a link to the Understanding of Marine Imagery sub-Facility and broader remit of the AUV Facility.

Ocean Gliders

Ocean gliders operate by moving ballast within the vehicle to facilitate gliding ascent and descent through the water column, and collect observations to deliver ocean profile data. IMOS gliders are instrumented to collect surface and sub-surface temperature, salinity, dissolved oxygen, current and chlorophyll data. Gliders have some advantages over shipborne data collection since they can be deployed into inclement weather where vessel operation may be unsafe. IMOS gliders have been used heavily to examine boundary currents in Western Australia and New South Wales, but there is scope for broader use of this capability.

For example, in addition to repeated sampling of set transects, IMOS has invested in the capacity for gliders to conduct event-based sampling. Use of gliders to provide enhanced data about marine heatwaves has demonstrated the capacity to respond to extreme or novel events and collect data important to understanding the impacts and implications of these events. There is scope for IMOS to continue and extend event-based sampling efforts to help understand these increasingly common events and the implications for ecosystems and management.

Animal Tracking

IMOS' Animal Tracking Facility is comprised of two components: satellite animal tagging and acoustic animal tracking. IMOS satellite animal tagging efforts are focused on Weddell and southern elephant seals in the Antarctic. Individuals are fitted with a tag that records the latitude and longitude location of the animal as well as temperature, conductivity, depth and fluorometry which can be used to characterise the water column. The diving behaviour of the seals provides water column profile data in regions that are often difficult to sample using other methods (e.g. at the ice edge). The data collected help describe the areas used and preferred by the seals, but also have the capacity to contribute to oceanographic modelling. Oceanographic data collected by seals and other marine animals have recently been formally recognised in the Global Ocean Observing System Observations Coordination Group, and are now included as an emerging network. This recognition suggests a broader role for these data beyond understanding animal behaviour.

The acoustic animal tracking component is the implementation of a national network of acoustic receiver installations capable of detecting individuals fitted with acoustic transmitters to track their movements. Acoustic tracking is most commonly applied to fish and shark species, although it can also be used to track movements of marine reptiles and invertebrates. IMOS supports the installation and maintenance of acoustic receivers, but does not fund acoustic transmitters and as such, this facility is heavily reliant on researchers within the community to partner with IMOS and share their data. The acoustic tracking community in Australia has evolved with IMOS and there is now a strong spirit of partnership and collaboration. Given the strong linkages of acoustic tracking to monitoring species of importance to fisheries, the IMOS acoustic receiver network was reconfigured in 2019 to enhance our ability to meet the needs of fisheries agencies. This realignment of the network, in conjunction with concerted efforts to fund a national pool of acoustic transmitters targeted at providing fisheries relevant data, is helping to increase the relevance and importance of this sub-Facility.

Ocean Radar

Ocean radar systems transmit high frequency radar signals from shore-based antennae to record and ultimately map surface currents in the upper 1-2 m of water. Coastal radar arrays are used to map surface currents at the mesoscale (typically 150 x 150 km) to help identify localised ocean surface conditions. IMOS has been working to establish and subsequently grow radar installations for over a decade. The network currently consists of eight installations primarily located in Western Australia, South Australia and New South Wales. There are a range of applications for radar data including on water operations by industries. We will also explore how this Facility relates to new approaches to understanding coastal conditions such as Satellite Remote Sensing wind and wave data and low-cost wave buoys.

Marine Microbiome

In partnership with Bioplatforms Australia, IMOS has been sampling the marine microbial community via the Marine Microbiome Initiative. The intent of the Marine Microbiome Initiative is to support our understanding of ocean health, biochemistry and primary productivity. Sampling at IMOS National Reference Stations and other coastal sites has been used to help establish a time series of marine microbial communities in Australian waters and their trends over time. Through coupling microbiome data with variables measured at National Reference Stations we can define baselines, trends and changes relevant to ecosystem health. In addition to helping understand ocean conditions, this initiative is developing a genomic resource for research, monitoring and management applications.

New Technology Proving

The New Technology Proving Facility within IMOS provides the capacity to pilot new technologies, methods or approaches to help improve the efficiency or effectiveness of IMOS or fill current observing gaps. The Facility is designed to enhance the IMOS program and provide the capacity to create additional impact.

The existing New Technology Proving Facility has trialled of a number of new technologies and methods with potential to improve the effectiveness or efficiency of the IMOS program. At the conclusion of New Technology Proving projects the IMOS Office considers whether the approach warrants inclusion in the IMOS program, and if there is scope to integrate successful elements in the future. For example, the success of a wind speed and direction project and use of the delivered outputs, provides a strong basis for expanding the Surface Wave sub-Facility to incorporate these approaches. Other elements of previous New Technology Proving projects may be integrated into scoping studies as a mechanism to trial broader integration of these elements in the IMOS program.

Emerging Priorities

There are a range of emerging priorities IMOS will work to integrate into the program. Due to funding uncertainties beyond the 2022/23 Financial Year it is difficult to determine the scale and scope of the investment in these areas. Therefore initial efforts will focus on a staged entry or completion of scoping studies to determine the applicability and feasibility of new elements. This approach will allow a period to assess the integration of these activities with other elements of the IMOS program, examine initial use and uptake by stakeholders and end users, and determine the potential to create societal benefit. Below we outline these emerging priority areas.

Coastal observing

There are numerous drivers compelling IMOS to conduct additional coastal sampling and observing. These include recommendations in the National Marine Science Plan (2015) and the 2016 National Research Infrastructure Roadmap. Ocean conditions have direct and sometimes significant impacts on coastal habitats ranging from inundation and loss of critical habitat such as seagrass and mangroves, to coastal erosion and sediment transport. The effects of the ocean on coastal systems are observed most dramatically during strong storm events as wind and waves can quickly alter coastal habitats. There is strong interest from a wide range of stakeholder and end-user groups to increase our understanding of coastal dynamics and potential impacts for coastal populations, coastal development and overall health of coastal ecosystems in areas where human pressures are greatest.

Based on the ongoing and increasing need for coastal observing IMOS will establish capability or play a coordinating role in nationally coastal observing to fill current gaps. IMOS will undertake a program that includes a number of elements/platforms in an integrated approach. The scope and scale of the program will be determined by stakeholder and end-user needs, existing coastal observing programs and identification of areas where IMOS can play a key role to enhance our national approach. The program will work to facilitate physical and biological observing and include engagement with a range of collaborators and stakeholders including scientists, managers, Traditional Owners and citizen scientists. An integrated and cooperative approach will facilitate collaboration, co-design and co-investment with a range of institutions and agencies interested in coastal observations. The collected data will help define the level of change occurring in coastal systems and implications for communities and habitats into the future. The advent of coastal observing provides capacity to link with other NCRIS capabilities such as the Terrestrial Ecosystem Research Network, AuScope, Australian Urban Research Infrastructure Network and the Atlas of Living Australia.

Event-based sampling

Extreme weather events are increasingly common and can have wide-ranging implications for marine habitats and species as well as the businesses and industries that rely upon them. IMOS collects observations on marine heatwave events as part of the Ocean Glider Facility, but there is potential to expand our approach and include additional changes or disturbances. In addition to marine heatwaves, event-based sampling could include freshwater runoff events, harmful algal blooms, storm effects and more. IMOS will explore approaches to monitoring and better understanding these events.

Molecular observing

Ongoing advances in genetics and sample processing are increasing the potential applications for marine molecular observing. Through collection of water samples at National Reference Stations and coastal sentinel sites, IMOS has the capacity to support molecular observing to help understand the composition and variability in marine microbial communities and examine biodiversity more broadly via environmental DNA (eDNA).

IMOS has already invested in marine microbial sampling in partnership with Bioplatforms Australia via the Marine Microbiome Initiative. In addition to microbes, IMOS will also explore eDNA analysis of water samples to help describe biodiversity. Through identification of DNA fragments shed by individuals in the region captured in water samples, eDNA helps define animal presence and community composition. eDNA sampling could create additional capability and observations relevant to stakeholders and end-users who manage and monitor communities and ecosystems. Coupling molecular observations with physical and chemical observations provides the capacity to explore the influence of environmental conditions on community composition and variation.

Sea Country observing

There is growing acknowledgement of the importance of recognising the rights and needs of Traditional Owner communities relative to their sea country. The nature of the IMOS program is such that we are continually operating within sea country areas and therefore have a role in working with Traditional Owner groups to help communicate what we are doing and how it relates to understanding and management of sea country. Expansion into coastal waters increases our overlap with and exposure to Traditional Owners and their sea country. Engagement and co-design with Traditional Owner groups will be an integral part of IMOS coastal observing.

IMOS will work with Traditional Owners and help facilitate partnerships within the IMOS community to deliver relevant sea country observations. There is potential for partnership with the Great Barrier Reef Foundation and others to leverage and extend our funding in this area.

Marine plastic and debris

Marine plastic pollution is a global issue that is receiving recognition from a range of national and international initiatives. The situation is so extensive that marine debris has been proposed as one of the Essential Ocean Variables by the Global Ocean Observing System. Within Australia there are a number of waste action proposals and initiatives including a Threat Abatement Plan under the Environment Protection and Biodiversity Conservation Act related to impacts of marine debris on wildlife in Australia's oceans. Therefore, there is a need to understand the level of marine plastic pollution affecting Australian waters, what the source of that plastic is, ongoing implications of marine plastic to species and people, and whether mitigation efforts are working to improve the situation.

The multiple drivers to understand implications of marine plastic pollution on Australia's ocean environment underpin an IMOS scoping study on marine plastic. This program will build on the body of work already being directed at marine plastic pollution and capitalise on the experience and expertise in the IMOS community, including provision of advice on using consistent data collection methodologies. Other types of marine debris will also be considered such as the presence of micribres. This scoping study will explore establishment of a national data repository for sustained marine plastic data records. By hosting data from sustained plastic observing programs IMOS can fill a national need and priority under the marine debris threat abatement plan. In addition, the program will consider building on and extending beyond the current marine microplastic New Technology Proving project. The combination of a national data repository and directed sampling that fills gaps not currently covered in existing programs will lead to a more comprehensive, national understanding of marine plastic and debris data. This area of observing provides strong potential for increased collaboration and partnership within and beyond the current IMOS community.

Data Delivery

As IMOS moves into the next five years we will continue to collect and deliver data, but we will also focus on how we can increase integration and use of the data we collect. We will do this by engaging with various segments of end-user communities, including research partners, and policy and decision-makers, but also by communicating more broadly with the general public to increase ocean awareness. There are increasing calls for real-time data to help inform operational activities. As technology advances and the IMOS program evolves we will continue to explore avenues for delivering data in real or near real-time to help better support maritime operations.

Data delivery and data products for use by marine scientists, industry, stakeholders and end-users is a fundamental element of IMOS. The Australian Ocean Data Network (AODN) provides a vehicle for IMOS data management, processing, delivery and access. It is important that IMOS data are made openly available and can be discovered, accessed, used and re-used. IMOS operates the AODN at the program level in conjunction with the IMOS Office. This arrangement supports connectivity among the AODN, IMOS Office and Facilities to ensure priorities are understood and met. Delivery of a program as broad and diverse as IMOS requires an adequately resourced and supported data infrastructure. The activity and success of the AODN is crucial to the success of the overall IMOS program, therefore, the AODN will continue to be a priority for funding, development and enhancement into the future.

Digital resources

In conjunction with the AODN, IMOS delivers several digital resources that help provide specific data elements to user communities and/or produce synthesis products for use. Current IMOS Digital Resources include the Understanding of Marine Imagery and National Reef Monitoring Network sub-Facility databases described under the AUV program, the Water Sampling Database associated with the NRS system, the IMOS Ocean Observer New Technology Proving project, the Australian Animal Acoustic Telemetry Database, and IMOS OceanCurrent. These resources are highly valued within and beyond IMOS and are integral to the success and expansion of IMOS' influence and impact.

Data products and services

As IMOS works to create societal benefit and support real-world change based on our observations, we are faced with the issue of how to deliver data to the people who make operational and management level decisions. While delivery of raw data streams is highly beneficial to researchers, these data are often less applicable for individuals in industry, policy, and management. Through engagement with stakeholders it is evident that there are distinct needs for integration of data streams to create syntheses and value-added data products. To meet this need, IMOS is employing a more end-to-end approach through data products and services that can be readily used by non-scientists including industries, citizen scientists and the public.

Data integration and synthesis will not only benefit end-users, they will also benefit non-specialist scientists. For example, integration of biological data on zooplankton with physical data on ocean currents and conditions will be beneficial to biologists unfamiliar with manipulation of oceanographic data. The integration of these data sets provides additional power to explain the patterns and distributions of species based on environmental conditions, thus adding value to both the biological and physical data that IMOS is collecting. These integrated data streams will make it easier for end-users to see the influence of the environment on these species without requiring specialist analytical skills, increasing the use and reach of IMOS observations.

By delivering IMOS data in an easier to digest manner we can increase the use, uptake and exposure of IMOS observations and their importance for Australia and our regional neighbours. An increased focus on data products and services will integrate directly with the AODN. This approach will allow the AODN to maintain focus on delivering the high-quality data needs of the research community and operational partners, while the data services program can focus on delivering products and platforms.

It is envisioned that through delivery of data products and services IMOS will more readily facilitate the transfer of data into knowledge and knowledge into decisions. This pathway from data delivery to use is essential to policy development and decision-making to ensure sustainable use and effective management of our marine estate. IMOS will continue to play a critical role in supporting this process and in the next five years we will increase our reach and influence in knowledge transfer in university, industry and policy domains.

IMOS

Integrated **Marine Observing** System

NCRIS National Research Infrastructure for Australia

An Australian Government Initiative

Australia's Integrated Marine Observing System (IMOS) is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent. **www.imos.org.au**

PRINCIPAL PARTICIPANTS

University of Tasmania (Lead Agent)

Australian Government

Australian Institute of Marine Science

Australian Government Bureau of Meteorology

CSIRO

Government of South Australia

SARDI South Australian Research and Development Institute

The University of Western Australia

sims sydney institute of marine science

UTS

The University of Sydney

Macquarie University

UNSW Sydney

SIMS is a partnership involving four universities.

ASSOCIATE PARTICIPANTS

Curtin University

Australian Government Department of Agriculture, Water and the Environment Australian Antarctic Division

Australian Antarctic Program

Deakin University

The University of Melbourne

IMOS thanks the many other organisations who partner with IMOS, providing co-investment, funding and operational support, including investment from the Tasmanian, Western Australian and Queensland State Governments.