



# Integrated **Marine** **Observing** System

## ***Five Year Plan (2017-22)***

**NCRIS**  
National Research  
Infrastructure for Australia  
An Australian Government Initiative

IMOS is supported by the Australian Government. It is led by the University of Tasmania on behalf of the Australian marine & climate science community.



**UNIVERSITY** of  
**TASMANIA**

## Executive Summary

The purpose of the IMOS Five Year Plan (2017-22) is to prepare for the opportunity to secure multi-year funding from the National Collaborative Research Infrastructure Strategy (NCRIS), expected to be available after the next Federal Budget in May 2017. And to take full advantage of the collaboration and co-investment opportunities that multi-year NCRIS funding will provide.

The process to develop this plan commenced in November 2015 with the IMOS Advisory Board reviewing and reconfirming the IMOS Strategy (2015-25) in the context of an emerging National Innovation and Science Agenda. Planning guidelines were developed during early 2016 and discussed at the Annual Planning Meeting in Hobart on 8-10 March. Consultations were then undertaken with all Nodes and targeted workshops held on key issues. A call for proposals was made on 16 May with a deadline of 10 June. Proposals received were then worked into a First Draft Five Year Plan made available for comment on 24 June with a deadline of 22 July. Through various mechanisms, the draft plan was made available to ~60 organisations that are users and stakeholders of IMOS, and 26 written responses were received. Feedback provided has been taken into account in this version of the plan, approved by the IMOS Advisory Board on 22 September 2016.

The plan is in four sections.

Section One provides a brief summary of the current status of IMOS as national research infrastructure. It describes the background and history, and explains the IMOS Strategy (2015-25) which is based around need, capability, and impact. The key point is that IMOS is clearly focused on being a national research infrastructure that has measurable impact.

Section Two makes the case for IMOS to be maintained as a world class research infrastructure, in line with the National Innovation and Science Agenda and its ongoing commitment to NCRIS, backed by funding of \$1.5 billion over the next decade.

It identifies key drivers, with emphasis on the Innovation Agenda, the related Research Infrastructure Roadmap, the National Science and Research Priorities, and the National Marine Science Plan. A more comprehensive set of drivers is included as an attachment, reflecting the full range of interests of all co-investors and partners in the IMOS national collaboration. However the emphasis on these four key drivers is considered to be appropriate given that the purpose of the plan is to secure future funding from NCRIS. Without core investment there will be no IMOS in which to co-invest. This section also identifies the major feedbacks that IMOS needs to respond to from within the observing system itself – nationally and internationally. It places particular emphasis on the concept of IMOS as a ‘dynamic infrastructure’. One that uses structured assessment of technical readiness (mature, pilot, proof-of-concept) to continually evolve the system in response to new scientific understanding, technological innovation, and new requirements.

Section Three is the bulk of the plan, and sets out a proposed portfolio of IMOS Facilities for the 2017-22 period. It uses a structure of ‘Broadscale’ observing, national ‘Backbone’ facilities, and ‘Regional’ intensification, to look into the substantial body of existing IMOS planning and performance information and identify the highest priorities for the future. Program Level issues are also considered. Broadscale, Backbone, Regional and Program Level facilities are then analysed in some detail, in four separate sub-sections.

Significant emphasis is placed on focused continuation of existing IMOS Facilities where this is warranted. Opportunities for improvement and areas which will be de-emphasised are also noted. It is important to understand that focused continuation of IMOS research infrastructure does not mean ‘*status quo*’ for the science and research output, and the impact it will have. In fact this will

increase dramatically as the datasets and time series are used and reused, extended, and integrated. This has already been demonstrated through measurement of increased scientific output and impact over ten years to date. IMOS is now the custodian of nationally and globally significant datasets and time series which did not exist ten years ago. The next decade will provide many new and exciting opportunities to exploit this research data infrastructure.

Attention is also paid to priorities for enhancing IMOS to do new things, and for extending existing facilities to provide increased spatial/temporal coverage where justified. This is a multi-year plan with a decadal outlook and needs to have a bold vision.

The plan is not 'costed' *per se*. We do not yet know the level of NCRIS funding available to IMOS, nor the level of co-investment available from partners. However the financial information we do have enables us to provide quantitative estimates of overall scale, and of relative trajectory of future investment across facility portfolio.

For each sub-section - Broadscale, Backbone, Regional and Program Level – there is a high level summary of the current facility portfolio and a pie chart showing relative distribution of resources required for focused continuation where this is warranted. There is also a summary of proposed enhancements and extensions, and a bar chart showing an indicative level of relative resources required. Priorities identified in the Summary are then supported by Detailed Analysis.

The intention is to give a sense of the emphasis and trajectory of the proposed IMOS portfolio over the 2017-22 period, which has now been tested against user and stakeholder expectations. It gives an indication of the scale of investment required to meet identified user and stakeholder needs.

The final section, Section Four, focuses on portfolio balance. It reviews all dimensions of the plan from a whole-of-IMOS perspective so as to consider whether it is well-balanced in terms of the major considerations for the future.

In summary, we believe that this Five Year Plan (2017-22) makes a strong case for IMOS to be maintained as a world class research infrastructure into the next decade.

**Prepared by: IMOS Director and IMOS Office staff,  
based on input from the Australian marine and climate science community  
and feedback from users and stakeholders**

**Published: 23 September 2016**

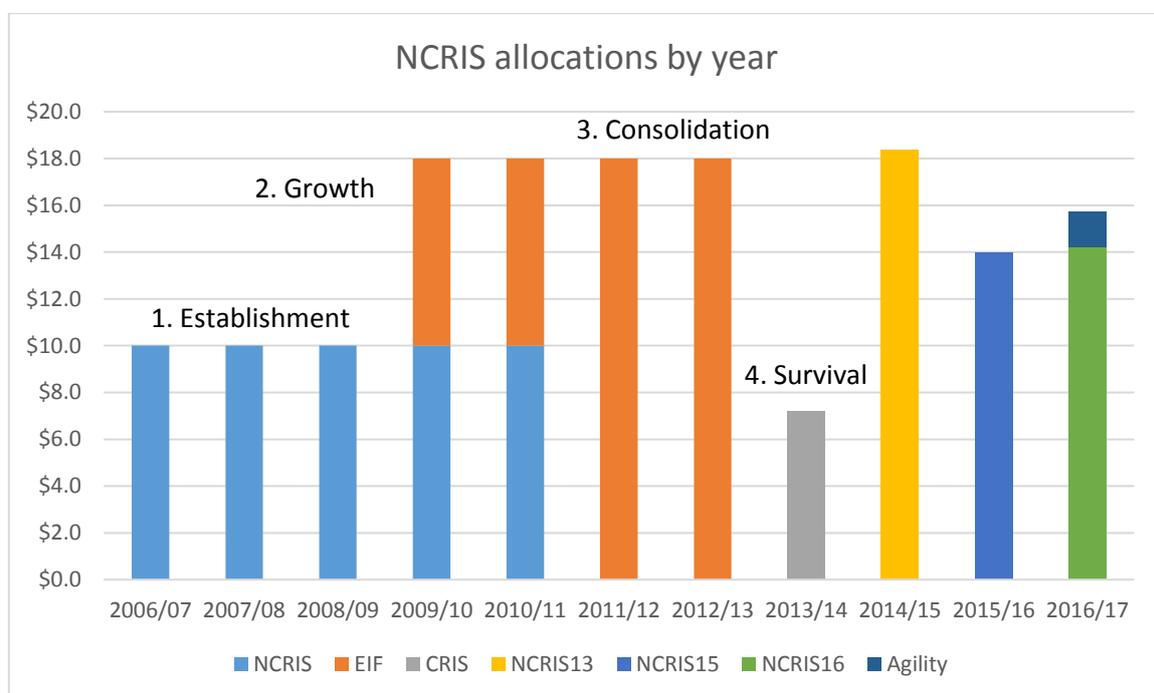
## 1. Current status of IMOS as a national research infrastructure (June 2016)

IMOS is one of the twelve foundation NCRIS capabilities established in 2006-7 in response to the first [strategic roadmap](#). By all objective measures, it has become a high performing national research infrastructure.

IMOS addresses multiple, national science and research priorities across Australia’s vast and valuable marine estate. The decadal [National Marine Science Plan \(2015-25\)](#) includes sustaining and expanding IMOS as one of its eight high level recommendations.

IMOS also provides a mechanism for the international collaboration required to understand a globally connected ocean. Since 2014, it has been recognised by the United Nations as one of thirteen regional alliances of the [Global Ocean Observing System](#).

At the time of writing this plan, IMOS has just completed its first decade of operation. Funding has come in four distinct phases (see graph below).



\$50M was allocated over five years in the establishment phase (2006-11). IMOS funding was then grown to \$18M *per annum* under the 2009 marine and climate super science initiative. This growth was successfully implemented in 2009-11 and the expanded program was consolidated during 2011-13. This is ‘IMOS’ as we know it today. Like all NCRIS capabilities, IMOS has been in survival mode in recent years, and the ongoing commitment to NCRIS is very welcome (see next section).

Notwithstanding recent funding uncertainty, IMOS has continued to make long term plans as appropriate for a large, sustained, observing system with strong international connections. The [IMOS Strategy \(2015-25\)](#) sets out the following vision:

*By 2025, Australia will have a continuously growing time series of essential ocean variables for marine and coastal environments. This will enable cutting edge research on contemporary problems, and provide a scientific basis for informed decision making about our vast and valuable marine estate.*

The IMOS Strategy is based around three strategic imperatives i.e. Need, Capability, and Impact.

## Need

As noted above, the need for IMOS has been established in the context of successive research infrastructure roadmaps, national science and research priorities, national marine science plans, and global ocean observing requirements. Over the last decade, the IMOS community has continued to plan ahead, routinely assess performance, and engage with users and stakeholders. As such, we are confident that 'IMOS 2016' is responding to contemporary needs.

## Capability

The capability established through IMOS has a number of distinctive, interacting elements i.e.

### **Facilities, Nodes, Partners, Data, and Leadership.**

IMOS currently has a portfolio of ten **Facilities** that undertake systematic and sustained observing of Australia's marine environment, across scales (from open ocean, onto the continental shelf, and into the coast), and across disciplines (physics, biogeochemistry, and biology and ecosystems).

These Facilities have [operating institutions](#), which include seven Universities, three publicly funded research agencies (PFRAs), two federal, one state, and our national metocean agency. Collectively, they provide a capability that was unimaginable before NCRIS was established and provided the incentive to build national research infrastructure through collaboration, not competition. The Australian marine and climate science community has embraced the NCRIS model, and IMOS is the result.

The current IMOS Facilities are:

1. [Argo Floats](#)
2. [Ships of Opportunity](#)
3. [Deep Water Moorings](#)
4. [Ocean Gliders](#)
5. [Autonomous Underwater Vehicles](#)
6. [National Mooring Network](#)
7. [Ocean Radar](#)
8. [Animal Tracking](#)
9. [Wireless Sensor Networks](#)
10. [Satellite Remote Sensing](#)

There is potential to grow the available capability by bringing additional operating institutions into the national collaboration e.g. the Australian Antarctic Division, and other Universities.

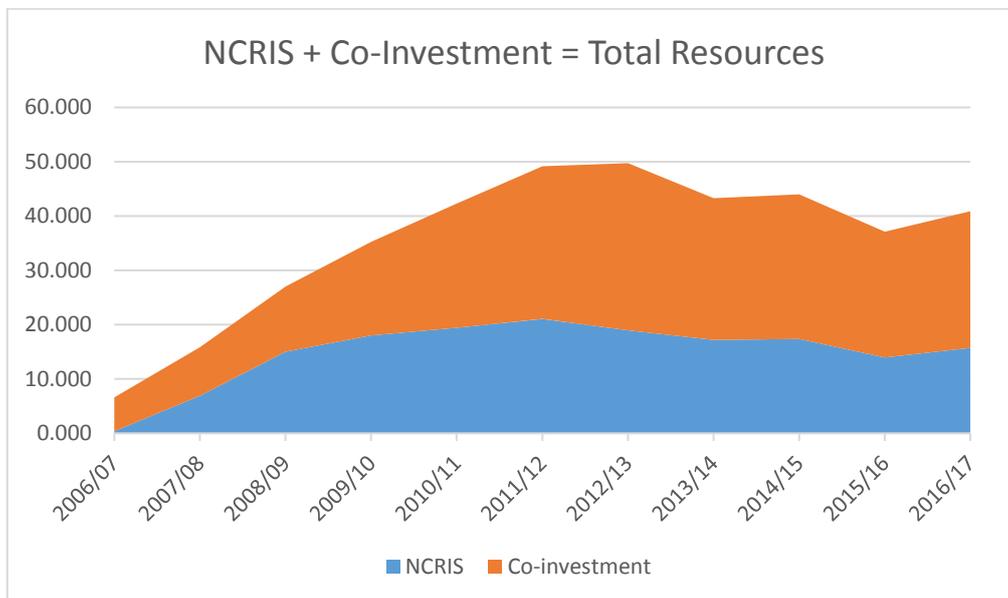
The Australian marine science and stakeholder community is large, diverse, and dispersed. **Nodes** provide the means for IMOS to undertake national science and implementation planning, integrated across regions. They identify the major research themes and science questions (i.e. the why?), and determine what we need to observe, where, when and how. IMOS [Node science and implementation plans](#) have continued to be reviewed and developed over a number of years. In total, they represent 650 pages of high quality, internationally peer reviewed planning that provides a tremendously strong scientific underpinning for IMOS.

Nodes are also the primary mechanism for growing the IMOS user base. Operated by eleven organisations, IMOS is currently used by another 103 national partner organisations and 95 international collaborating organisations. It has ~2,200 individual/group users.

The current IMOS Nodes are:

1. [Bluewater and Climate Node](#)
2. [Queensland's Integrated Marine Observing System \(Q-IMOS\)](#)
3. [New South Wales Integrated Marine Observing System \(NSW-IMOS\)](#)
4. [Southern Australian Integrated Marine Observing System \(SAIMOS\)](#)
5. [Western Australian Integrated Marine Observing System \(WAIMOS\)](#)
6. [South East Australia IMOS \(SEA-IMOS\)](#)

**Partners** include the operating institutions, but also [operational partners](#) who provide additional capability, [international collaborators](#), and [other investors](#). Collectively these partners have co-invested \$1.40 for every NCRIS \$1.00 invested in IMOS to date (see graph below). IMOS only exists because of NCRIS, but it is clearly seen as a significant community asset by marine and climate scientists and stakeholders, regionally, nationally and globally.



A key element of IMOS is that all observations are turned into **Data** that can be discovered, accessed, downloaded, used and reused in perpetuity. Datasets and time series are essentially the research infrastructure that is being created and developed. This has been achieved by having a separate Data Facility that is responsible for building and maintaining a national marine information infrastructure. The infrastructure includes a geospatial portal as well as a metadata system, file formats, controlled vocabularies, file storage, servers, web services, and data tools.

Since 2011, IMOS has had responsibility for managing Australia's national ocean data facility, including metadata and data from many other organisations. Previously separate infrastructures have recently been merged into a single national marine information infrastructure called the [Australian Ocean Data Network \(AODN\)](#), operated as a Facility of IMOS. Enabling open access to marine data, regardless of who funds the acquisition, is considered to be core business for IMOS on an ongoing basis. A major pathway for growing the system will be through 'co-investment' of marine data collected by university, government and industry partners.

**Leadership** is provided by the IMOS Office based at University of Tasmania and assisted by an independently-chaired Advisory Board. The Office is responsible for managing NCRIS funding agreements executed with the Australian Government Department of Education and Training, as well as agreements with operating institutions and relationships with many other partners. The

IMOS Office is clearly focused on performance assessment so as to ensure that the system is actually delivering as planned, and that corrective actions are taken as required. Four performance indicators have been developed and are routinely assessed i.e.

1. [deployment and recovery of equipment](#)
2. [availability of data](#)
3. [uptake and use of data](#), and
4. relevance and impact of science outputs (see next section).

## Impact

IMOS is a national research infrastructure that is widely used by the research community to deliver science outputs of relevance to users and stakeholders. IMOS articulates its pathways to impact through the 'circle diagram' (shown below), designed to be read from inside to out.

It illustrates how the system is operated by a small number of institutions with relevant expertise but is made available for use by all through broadly-based, community-driven planning and open data access. This enables IMOS partners to generate a wide range of science-based outputs, from peer reviewed publications to daily ocean forecasts. These outputs are used by institutions, projects, and programs to deliver impact across many sectors of government, industry, society.

The relevant sectors are shown around the outer ring of the diagram. IMOS can demonstrate its contribution to all of these sectors through a growing number of major [research partnerships](#) that effectively 'close the loop', from infrastructure to impact.



**In summary**, we are confident that as of September 2016, IMOS is meeting the contemporary needs of an extensive user and stakeholder base by providing high-performing research infrastructure capability that is connected to research of relevance across various sectors of government, industry and society.

## 2. Maintaining IMOS as a world class research infrastructure

In December 2015, the Australian Government released its [National Innovation and Science Agenda](#). The Innovation Agenda includes a commitment to “[maintaining world class infrastructure](#)”, to “provide long-term funding certainty for cutting-edge, national research infrastructure to ensure research jobs stay in Australia and Australia retains its world-class science and research capability”. Specifically, it includes an ongoing commitment to NCRIS backed by \$1.5BN of investment over the next ten years. It says that “\$1.5 billion will be provided to ensure that NCRIS continues to drive collaboration between researchers, government and industry to deliver practical outcomes...”. The new funding will commence from July 2017 at the level of \$150M *per annum* plus indexation i.e. \$153.9M in 2017-18.

The commitment to NCRIS is not a commitment to IMOS *per se*. A new [National Research Infrastructure Roadmap](#) is being developed during 2016 to guide future research infrastructure investment, including but not limited to the NCRIS funding. By all objective measures, IMOS is currently a world class research infrastructure, and it therefore has a strong case to be maintained under the Innovation Agenda. The IMOS Five Year Plan is being developed on that basis.

Noting that NCRIS funding has been announced for ten years, we expect it to be allocated on a five-plus-five-year basis. The IMOS Five Year Plan (2017-22) will be conditioned by the indicative level of NCRIS funding available over the next five years (estimated to be ~\$800M), plus potential co-investment from partners.

This is a multi-year plan with a decadal outlook and needs to have a bold vision. The Chief Scientist is urging us to ‘think big’ in the Roadmap. It needs to be understood from the outset that an allocation of NCRIS funding and a substantial level of co-investment and additional core investment would be required to implement this plan in full.

### Drivers (from a User and Stakeholder perspective)

IMOS has many partners and therefore many drivers (see Attachment 1). In securing its future as an NCRIS capability, IMOS must respond to the National Innovation and Science Agenda, the Research Infrastructure Roadmap (being developed around six capability areas), the National Science and Research Priorities, and the National Marine Science Plan – see below (most relevant priorities shaded blue):

Innovation Agenda	Infrastructure Roadmap	National Priorities	Marine Science
Collaboration	National Interest and Security	Transport	Marine Sovereignty and Security
		Cybersecurity	
Researchers	Underpinning Research Infrastructure	Energy	Energy Security
		Resources	
Government	Understanding Cultures and Communities	Food	Food Security
	Health and Medical Sciences	Health	
Industry	Environment and Natural Resource Management	Soil and Water	Biodiversity Conservation
		Environmental Change	Climate Change Adaptation
Practical Outcomes	Advanced Physics, Maths and Materials	Advanced Manufacturing	Resource Allocation
			Sustainable Urban Coastal Development

IMOS is able to respond to a very broad range of drivers because it is a large, national research infrastructure, operated and used by a mix of universities, PFRAs, government agencies and industry partners. It is therefore able to work across the spectrum from basic research and research training, to applied and mission directed research, to research with operational relevance.

The imperative to collaborate in support of practical outcomes for industry is understood, as is the need to provide research training for Australia’s future marine Science, Technology, Engineering and Mathematics (STEM) workforce. The opportunity to increase operational relevance through reuse of scientifically robust observations and data in near real time is being embraced, without loss of focus on the core mission as a national research infrastructure.

IMOS is, and should remain, big enough to respond to all of these drivers. This is how we capture the efficiency and effectiveness of having a single, national research infrastructure. It must continue to evolve, shifting emphasis and trajectory over the next five years as follows:

	<b>Evolving towards</b>	<b>Will require more</b>
<b>Basic research and research training</b>	Data literacy, STEM workforce, research training for industry	open data, virtual laboratories, real time data, autonomous marine systems (platforms and sensors), marine ‘omics, time series turned into value added products, remote sensing, fusion of models and data
<b>Applied and mission directed research</b>	Climate impacts/adaptation, seasonal/decadal timescales, environmental baselines	
<b>Research with operational relevance</b>	Safety and efficiency of marine industries, defence innovation	

## Feedbacks

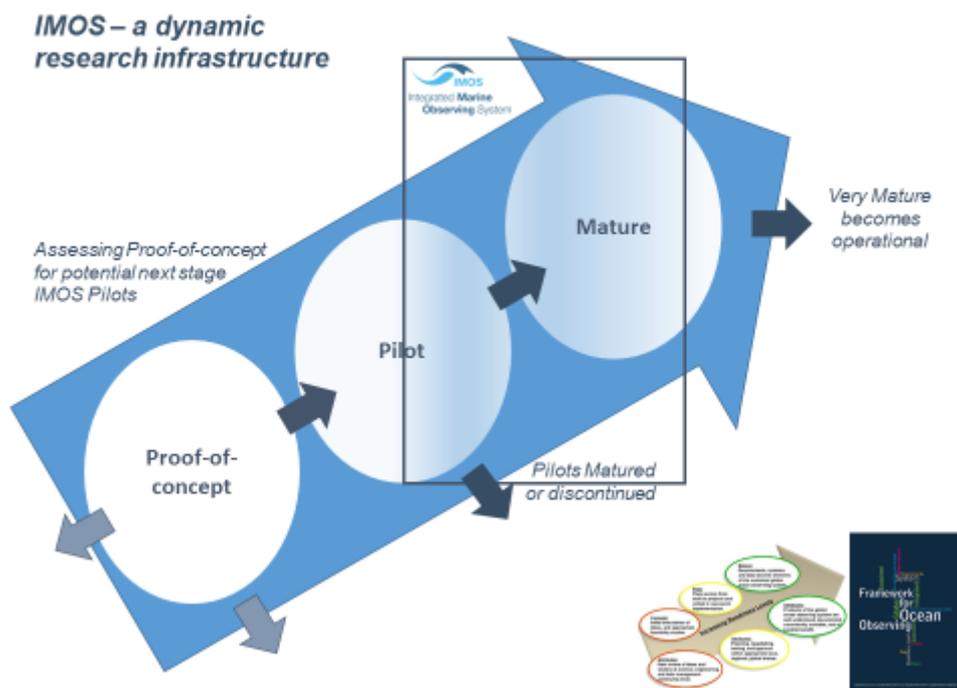
In addition to external drivers, the IMOS Five Year Plan needs to respond to feedbacks from within the observing system itself. This is particularly important because, like all NCRIS capabilities, IMOS has largely been in ‘survival’ mode over the last four years, with funding allocations made on an annual basis and often at quite short notice. Ongoing uncertainty about NCRIS funding has inevitably shortened our planning horizons, and with NCRIS funding certainty restored it is again time to make multi-year plans that address risks and issues in a strategic manner.

**Deferred capital replacement** is one issue that is well recognised across the NCRIS program.

Funding in recent years has basically been to operate and maintain the existing infrastructure. IMOS will need to address its deferred capital maintenance early in the five year planning period, and ensure that adequate allowance is made for planned capital replacement in the out years.

Noting that this may present some challenges in managing uneven cash flows across ‘flat’ (indexed) annual budgets, it will also present opportunities to reserve some level of investment for later years. As will be discussed later on, there are some areas where we know exciting developments are in the pipeline but will not be ready for adoption by July 2017. Within reason, IMOS would be wise to reserve some **future flexibility** to take up these opportunities, noting that it will require even stricter prioritisation in the early years.

This brings us to the important issue of ‘**readiness**’. Adapted from the [Framework for Ocean Observing](#) that guides the Global Ocean Observing System, the diagram below illustrates how IMOS uses the construct of readiness to ensure it remains a dynamic infrastructure, able to respond to new scientific understanding, technological innovation, and new requirements.



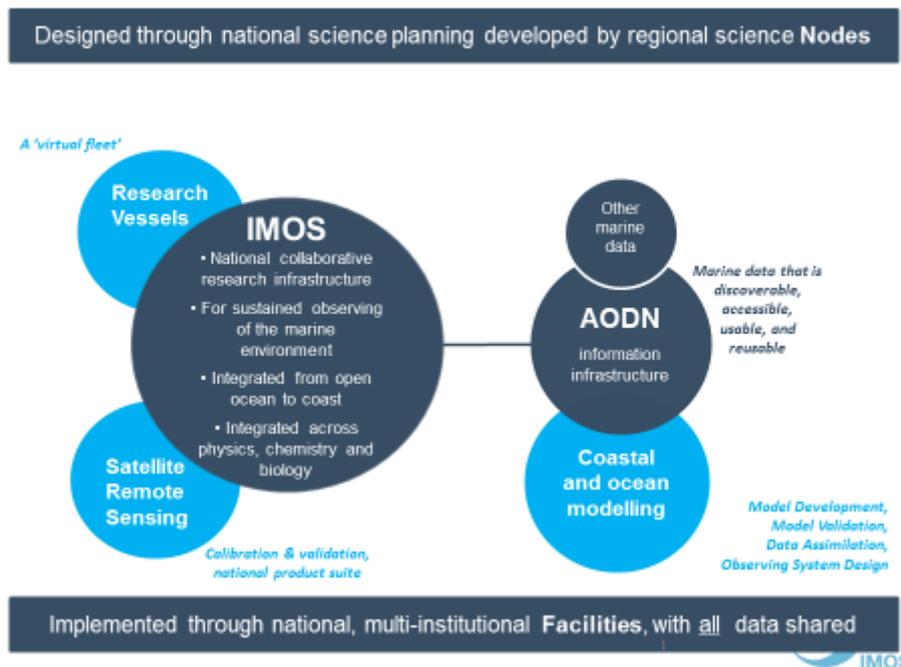
As a research infrastructure with operational relevance, IMOS will be heavily invested in mature Facilities. In this context, ‘mature’ means that requirements are clearly defined in terms of essential ocean variables (EOVs) to be measured, and observing technologies used are proven and reliable. IMOS needs a high degree of confidence that platforms and sensors deployed will perform in the field, and return data that can be used for science, research and teaching, and reused for other purposes. Where the operational utility of an IMOS Facility begins to outweigh its research utility, there needs to be a dialogue with the relevant operational agencies about shared investment. This is critical because the research infrastructure budget needs to be freed up for next stage investment (see below). The Bureau of Meteorology, Department of Defence, and IMOS are discussing establishment of an Australian Ocean Observing Partnership to facilitate exactly this kind of dialogue. Other lines of discussion will be established with partner agencies such as The Australian Antarctic Division and Geoscience Australia.

IMOS will also invest in pilot Facilities to test the utility of platforms and sensors in light of new scientific understanding, technological innovation, and new requirements. Consistent with comments above about the role of a national research infrastructure, IMOS needs to be somewhat conservative in its selection of pilots so as to ensure a reasonable degree of confidence that usable data will be returned. Within Australia, ‘piloting’ new platforms and sensors has been a particularly important role for IMOS. Our country does not have very large and wealthy institutions by global standards, nor a highly developed marine technology industry. A number of existing IMOS Facility investments have effectively brought new platforms and sensors to Australia and made them available to a broad science and research community for the first time. This is an ongoing role.

IMOS does not invest in proof-of-concept Facilities *per se*, for reasons outlined above. However we do want to engage with communities involved in proving new concepts that are highly relevant to the objectives of IMOS. These are the ‘laboratories’ that will produce next generation pilots. Significantly, the existing IMOS national research infrastructure can provide an excellent testbed for communities proving new concepts because of the infrastructure and data already available.

**Cost effectiveness** will always be a feedback for IMOS. Initially, the emphasis was on reducing the cost per observation. As the system has matured over time we have placed increasing emphasis on the relationship between cost and impact, using our performance assessment systems to inform this analysis. Objective assessment of relative impact, related to relative cost, will influence prioritisation of existing IMOS Facilities in the Five Year Plan. Adoption of new, cost effective approaches will also be considered e.g. citizen science.

**Key dependencies** are another feedback that IMOS needs to consider in its forward planning, in terms of both threat, and opportunity. The capability diagram shown below (drawn from the IMOS Strategy 2015-25) illustrates that access to research vessels and data from foreign satellite missions, along with engagement of the coastal and ocean modelling communities, are the most critical dependencies.



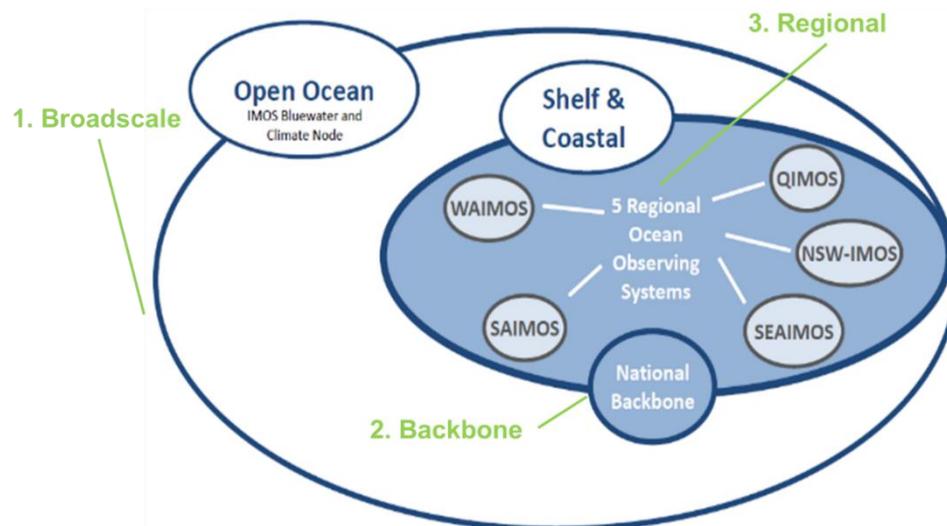
## Priorities

IMOS is a very 'scalable' research infrastructure. Once the core capability has been established and is functioning well, it can be readily expanded to include new geographic regions, new ocean variables, new platforms and sensors. This was demonstrated in 2009-11 when the funding was increased and the program was grown by 80% after just three years of operation. Scalability presents many new opportunities, but it also presents prioritisation challenges.

The burden of prioritisation within and across Nodes and Facilities falls quite heavily on the IMOS Office and Advisory Board. By design, IMOS funds (national) Facilities on the advice of Node science and implementation plans. The Node plans are not financially constrained. At inception it was decided that IMOS would not fund Nodes. It was posited that a Node funding model would never deliver national Facilities, and would tend to foster inter-nodal competition rather than community-wide collaboration. The current Node/Facility model has been made to work well with strong leadership and clear performance assessment criteria. However it does present challenges in prioritising across and within Nodes, and across and within Facilities. The IMOS Five Year Planning process needs to deal with this.

In developing this Draft Five Year Plan, we therefore called for proposals within a structure of Broadscale, Backbone and Regional facilities. Program Level facilities (AODN and IMOS Office) were also considered. This structure has the advantage of being well understood within the ocean observing community, yet cutting across the existing IMOS Node/Facility structure.

Broadscale facilities cover the open ocean and are globally connected. Backbone facilities link the Broadscale to the Regional, and provide national capability where a ‘sum of regions’ approach is inadequate for the questions to be answered. Regional facilities provide necessary intensification in areas of Australia’s marine environment with high social, economic and environmental value. The relationship between them is shown in the diagram below:



Within this structure of Broadscale, Backbone, Regional and Program Level facilities, priorities will be set for both focused continuation of existing activities, and enhancement to do new things, or extension to go into new areas.

IMOS is a sustained observing system which is building large datasets and time series. As such we expect to continue many activities already underway, always with an eye to increasing effectiveness and efficiency, and driving increased uptake and impact. We focus by maturing or discontinuing pilot activities, and considering operational utility of the very mature. This is what we mean by ‘focused continuation’.

IMOS also needs to take on new opportunities, in response to different policy drivers, changes in scientific understanding, and technological innovation. This must include some enhancement of IMOS to do things we have not done before, taking on new pilots where proof-of-concept has been demonstrated, or mature activities successfully piloted in other contexts. It may also include extension of the continued program to provide increased spatial and/or temporal coverage where there is a particularly strong user/stakeholder demand.

**In summary**, based on current status, available NCRIS funding and potential co-investment, and strategic responses to drivers and feedbacks, a prioritised Five Year Plan is set out in the following section, aimed at maintaining IMOS as a world class research infrastructure.

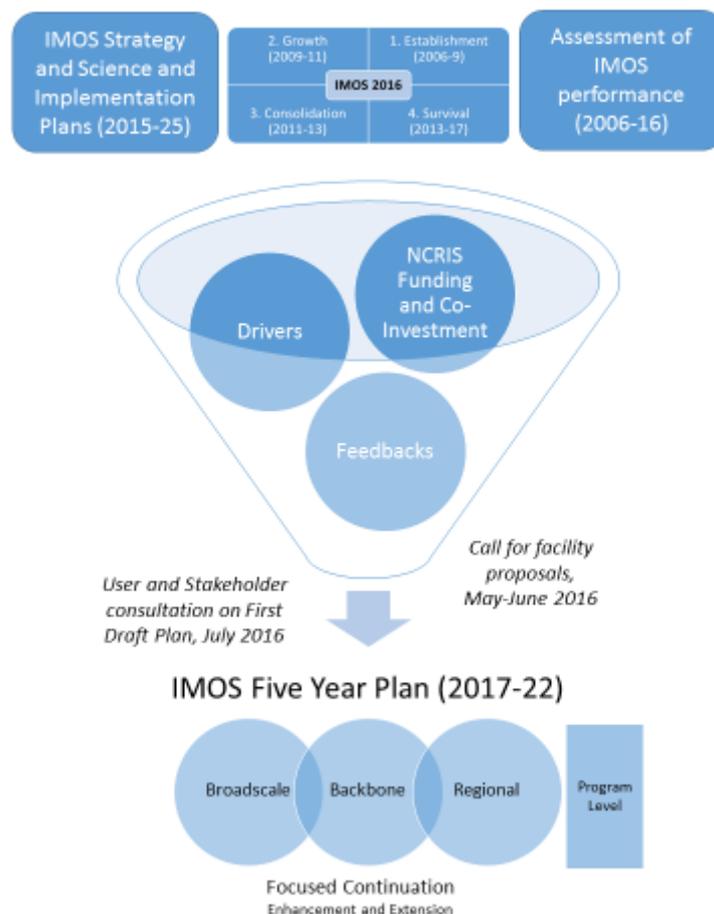
### 3. Proposed IMOS Facility Portfolio (2017-22)

In this section, we summarise current thinking about a proposed IMOS Facility Portfolio for the next five years (2017-22).

It takes into account the current status of IMOS in 2016, and the rich body of forward strategy and science planning, and assessment of performance, that has already been undertaken. It recognises the current NCRIS funding context and need for co-investment, and responds to contemporary drivers within the national innovation system as well as specific feedbacks in an ocean observing system context. It also makes use of additional information provided in a recent call for facility proposals.

This has led to a proposed IMOS Facility Portfolio (2017-22) with Broadscale, Backbone, Regional and Program Level components, and priorities for focused continuation, and enhancement and extension.

The process to develop the proposed Facility portfolio is summarised in the diagram below:



N.B. Given that both the level of NCRIS funding for IMOS and the level of co-investment available from partners are currently unknown, this plan is not 'costed'. However financial information gathered during the call for facility proposals has been used to provide quantitative estimates of relative investment across facilities for both focused continuation, and enhancement and extension. The intention is to give a sense of the emphasis and trajectory of the proposed IMOS portfolio over the 2017-22 period, which has now been tested against user and stakeholder expectations. It gives an indication of the scale of investment required to meet identified user and stakeholder needs.

### 3.1 BROADSCALE

#### Summary

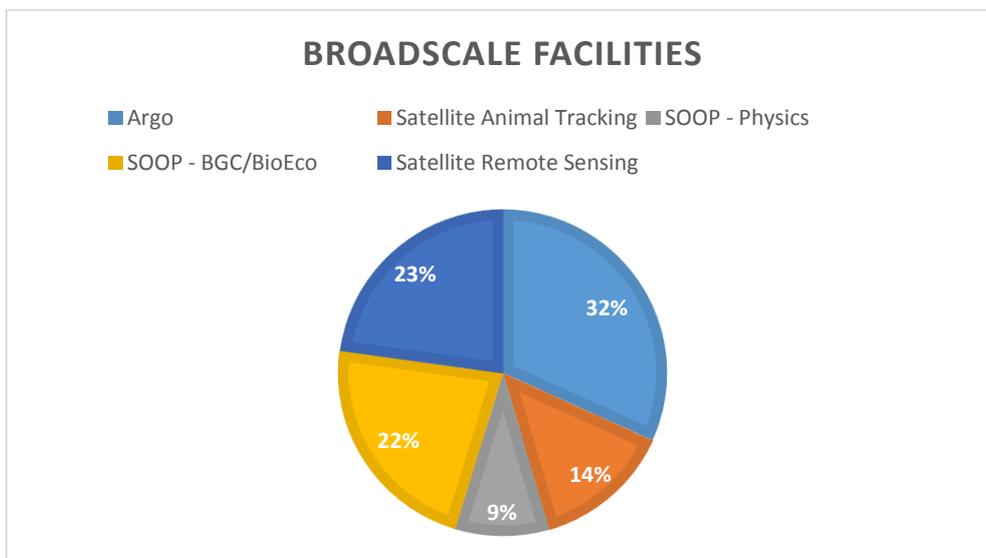
Broadscale facilities provide much of Australia’s contribution to the Global Ocean Observing System (GOOS), and related basin-scale coordination efforts in the Southern Ocean, Indian Ocean and Pacific Ocean. These facilities are embedded in the relevant international programs, and IMOS priorities are guided by internationally agreed system designs and the requirements of global products, analyses and modelling needed by Australian scientists, users and stakeholders. Engagement with the international space agencies and their civil Earth Observation missions is crucial, with respect to Sea Surface Temperature, Altimetry, and Ocean Colour, and potentially other variables as they mature (e.g. sea surface salinity, sea ice extent).

The Broadscale portfolio currently includes:

- Argo profiling floats
- Satellite Animal Tracking
- Ships of Opportunity, for physics
- Ships of Opportunity, for biogeochemistry and biology and ecosystems, and
- Satellite Remote Sensing, calibration/validation/reception and national products.

All of these facilities warrant focused continuation, noting various issues raised in the Detailed Analysis that follows.

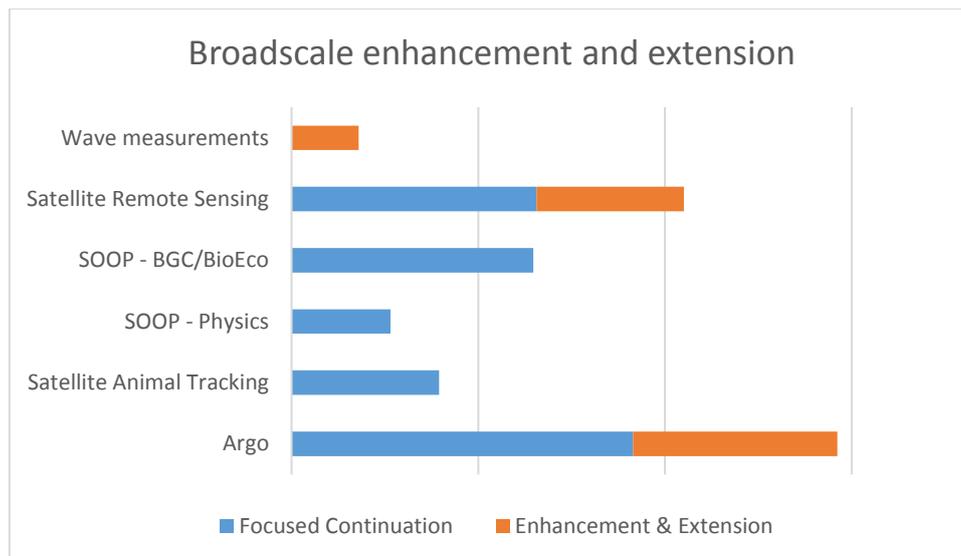
Relative distribution of resources required for focused continuation is shown below.



There is also potential to enhance and extend the Broadscale portfolio in response to drivers and feedbacks. Proposed priorities are summarised below, and elaborated in the Detailed Analysis:

1. Enhance Argo to include biogeochemical properties and deep ocean measurements
2. Extend Argo into the ice zone.
3. Enhance remote sensing to exploit data from new international satellite missions coming on stream, and engage with the sea ice community.
4. Enhance IMOS to begin investing directly in the measurement of waves.

An indicative level of relative resources required for enhancement and extension is shown below. Enhancement and extension is shown in orange bars, relative to focused continuation in blue bars (which correlate with the pie chart above).



## Detailed Analysis

**Argo profiling floats** provide a revolutionary capability to monitor the largescale temperature and salinity structures of the global ocean to 2000m depth on seasonal timescales and in near real time. This is particularly important for the Australian region given the paucity of subsurface observations in the Southern Hemisphere from other platforms (e.g. ships). Argo's core mission remains to measure temperature and salinity in the open ocean and ice free regions deeper than 2000m.

IMOS plans to continue providing the cornerstone investment (>50%) for Australia's ongoing participation in the global Argo program. Co-investment is expected to come from the research budgets of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC). Through the Argo Australia Facility, IMOS will also work with the Bureau of Meteorology and the Department of Defence to help secure reliable, multi-year co-investment in recognition of the operational utility of Argo. This is necessary if we are to free up research budgets to enable exciting new science opportunities (see below). IMOS, the Bureau of Meteorology and the Department of Defence have commenced discussions on the formation of an Australian Ocean Observing Partnership as a mechanism for effective and efficient government investment in an observing system that meets both research and operational needs.

In line with international developments, and following successful proof-of-concept activities in the Australian region, Argo Australia should be enhanced to commence regional pilots in biogeochemical measurements (Biogeochemical Argo), bio-optical measurements (Bio-Argo), and in deep ocean measurements (Deep Argo). Argo Australia should also be extended into the seasonal sea ice zone of the Australian sector of the Southern Ocean, following successful pilot activity in previous phases of IMOS.

**Satellite Animal Tracking** of Weddell and Elephant seals provides high resolution ocean observations in high latitudes that are difficult if not impossible to obtain by other means. It also provides information about the way in which these top predators use oceanographic features within the Southern Ocean ecosystem – an excellent example of the type of biophysical integration that IMOS strives to achieve. IMOS plans to continue this work in close collaboration with Argo (see above), the Australian Antarctic Division (who provide essential science prioritisation and logistical support) and the international community through the Southern Ocean Observing System (SOOS).

Use of **Ships of Opportunity to measure physics** is very mature. This includes routine sea surface temperature measurements from sensors on commercial and research vessels, and temperature profiles (to 800m depth) from expendable bathythermographs (XBT) using merchant vessels on high-resolution repeat lines. It also includes measurement of air-sea fluxes from research vessels operating in our region (Australian, French and New Zealand). All of these observations are well utilised within global systems and products which in turn deliver added value to the Australian marine and climate science community. Continued investment by IMOS as a reliable southern hemisphere partner in the global ocean observing enterprise is warranted. The Bureau of Meteorology and Department of Defence (amongst others) co-invest in this work, and IMOS will continue to discuss relative contributions to reflect both research and operational utility (see comments above under Argo). Consideration should be given to newer ship-based technologies in areas that are very mature e.g. underway CTDs (measuring conductivity, temperature, depth) for expendable bathythermographs.

Use of **Ships of Opportunity to measure biogeochemistry, and biology and ecosystems** spans a spectrum of maturity at BROADSCALE. Measurement of CO<sub>2</sub> is quite mature, with IMOS data feeding into a global Surface Ocean CO<sub>2</sub> Atlas (SOCAT). Continuous Plankton Recorders (CPR) are a very mature technology, but have largely been used in a regional context, most intensively in the northeast Atlantic and in the Southern Ocean. Echo-sounders on research and commercial/fishing vessels are also being used to provide information on distribution and abundance of mid-trophic (i.e. middle of the food web) organisms at basin scales.

Building on the long running Southern Ocean CPR survey operated by the Australian Antarctic Division (AAD), IMOS has piloted an extension of CPR onto the Australian continental shelf. Broad utilisation of this expanded dataset has been a little slow, in part because the processing of CPR samples remains very labour intensive. However the production of [Plankton 2015](#) was a major step forward, and we will seek feedback via the 2016 Australian Government State of the Environment Report in assessing the value of producing this report on a biennial basis. Work of the current IMOS Zooplankton Ocean Observing and Modelling ([ZOOM](#)) Task Team is also very relevant, as it will help to elucidate the utility of CPR (and other zooplankton) data for biogeochemical and ecosystem modelling. At the international level, zooplankton diversity and phytoplankton biomass/productivity are emerging as two candidate essential ocean variables for biology and ecosystems in GOOS. And in 2011, all of the long term CPR Surveys around the world formed a global alliance (called [GACS](#)) that should assist in moving towards a more global/broadscale focus. Interest has been expressed in IMOS driving closer coordination between CO<sub>2</sub> and CPR work, particularly in the Great Barrier Reef (GBR) region.

This Facility also includes underway measurements from the Australian Institute of Marine Science (AIMS) vessels (*RVs Cape Ferguson* and *Solander*) and the Bass Strait Ferry, *Spirit of Tasmania*. This work was considered in a Regional context during the call for proposals, and interest was expressed in enhancement to include pCO<sub>2</sub> and pH. On reflection, it is best to continue viewing them as part of the national/broadscale Ship of Opportunity fleet and consider new variables in that context.

In summary, continued investment by IMOS in coordinated Australian continental shelf and Southern Ocean CO<sub>2</sub> monitoring and CPR surveys will produce a dataset of national and global significance. Investment in *in situ* plankton recorders to monitor larger zooplankton not captured by CPR technology also needs to be considered.

IMOS has piloted the use of echo-sounders on research and commercial/fishing vessels to measure the distribution and abundance of mid-trophic organisms at basin scales. For the ecosystem modelling community, biomass of mid-trophic organisms remains a large uncertainty. Estimates from

various models vary by up to an order of magnitude, which is obviously an issue in terms of effective fisheries and marine ecosystem management. This uncertainty provides the context for the IMOS 'bio-acoustics' program. Good progress has been made in establishing relationships with vessel operators, calibration of equipment, collection and quality control of data, and publication of data and products (echograms). As with CPR, there is not yet broad utilisation of the dataset, and there is unrealised potential for collaboration in the Southern Ocean and Antarctic where use of acoustics to measure abundance of krill is more mature. The ZOOM Task Team and recognition of zooplankton diversity as an essential global ocean variable, both mentioned under CPR, are also highly relevant here. Significant steps will be taken through a large, multinational, multi-institutional project that has just been established in the Southern Ocean to couple acoustic observations with ecosystem modelling. This European Union (EU)-funded project explicitly recognises that IMOS has created an 'underlying structure to build on for global accessible acoustic data for model uptake'. In summary, continued investment by IMOS in a vessel based bio-acoustics program has the potential to produce a dataset of national and global significance.

**Satellite Remote Sensing** provides a uniquely efficient means of making repetitive observations automatically over vast areas of the ocean. Although confined to the surface layer, over the past 30 years these observations have been a vital tool for both biological and physical oceanographers and have played a major role in advancing marine and climate science. Australia does not have a national research satellite capability and so the role of IMOS is to enable closer collaboration with international space agencies to make more of their data of better quality, more available and easier to use for research in the Australian region. The IMOS Satellite Remote Sensing Facility achieves this through supporting calibration, validation and collection of satellite data, as well as its management and processing to provide properly documented data in standard formats that are widely supported and familiar to the Australian marine and climate science community and their international collaborators. The data management is done collaboratively within the NCRIS program, with the National Computational Infrastructure (NCI) and the Terrestrial Ecosystem Research Network (TERN).

As a marine observing system, the focus of IMOS is on sea surface temperature (SST), ocean surface height (Altimetry), and ocean colour radiometry (OCR). Other variables will need to be considered as they mature (e.g. sea surface salinity, sea ice extent).

SST and Altimetry are quite mature in the Australia context. The role of IMOS in (a) calibration/validation/collection, and (b) data processing/management/products, is well defined and appropriately linked to the relevant international science programs i.e. the Group for High Resolution Sea Surface Temperature ([GHRSSST](#)) and the Ocean Surface Topography Science Team ([OSTST](#)). New satellite missions recently launched are being accommodated (e.g. Sentinel 3A), and preparations are being made for upcoming missions (e.g. Sentinel 3B in 2017).

Further afield, the Surface Water Ocean Topography (SWOT) mission to be launched in 2020 will provide game changing capability in understanding of ocean circulation, and provides exciting potential for IMOS Altimetry work. There is potential to enhance the Altimetry calibration and validation Facility so as to obtain maximum benefit from SWOT's initial 'fast repeat' orbit during its calibration and validation phase. This orbit will pass over the established Bass Strait sites, but (fortuitously) also over the IMOS Southern Ocean Time Series and Yongala National Reference Station sites.

OCR is less mature in the Australian context, particularly in more optically complex ('case 2') waters where the accuracy and reliability of remote sensing products continues to be debated e.g. on the Great Barrier Reef (GBR). There is an effective international coordinating mechanism in place via the

International Ocean Colour Coordinating Group (IOCCG), and Australia's ability to engage at this level has been enhanced in recent years through strategic staff appointments and capability building at institutional level. The future of satellite OCR is going to include hyperspectral missions. Those missions have in general a larger remit than OCR only, yet could prove useful to improve ocean colour products in coastal waters. OCR observations from geostationary sensors (such as Japan's Himawari satellite missions) are also becoming part of the international panorama, although the level of coverage of Australian waters that will be provided is currently unclear.

IMOS has invested in a national Bio-Optical Database to house all *in situ* bio-optical measurements for the Australian region, linked to the requirements of relevant international space agencies, the US National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). There is potential to extend this to a 'match up' database to support regional OCR algorithm development and validation.

Investment in OCR at the Lucinda Jetty Coastal Observatory (on the GBR) and using shipboard instruments (called Dalecs) has been problematic for a range of reasons, and an IMOS national Task Team is being formed to review current investments in OCR (by IMOS and others). It will report in mid-2017.

Noting that IMOS supports the only satellite Altimetry calibration data stream in the southern hemisphere, there is currently no equivalent site for satellite OCR. All 'system vicarious calibration' for OCR missions is done from two northern hemisphere sites, in the Mediterranean Sea and off Hawaii. The recent and upcoming Sentinel satellite missions (3A and 3B) provide an opportunity to enhance the IMOS Rottneest Island National Reference Station to become a 'bluewater' Ocean Colour calibration and validation site. With co-investment from international space agencies, this could develop into a third, global, 'system vicarious calibration' site, the only one in the southern hemisphere.

Satellite OCR is not an end in itself, and the highly integrated nature of IMOS means that we are distinctively placed in global terms to work at the nexus of satellite remote sensing, *in situ* ocean optics, biogeochemistry and microbial ecology. Final decisions about future OCR investments will be carefully considered in this context. For example, Harmful Algal Blooms (HABs) are becoming a more significant issue in a warming ocean (including for the aquaculture and fishing industries), and the potential for IMOS to underpin research into HAB forecasting should be explored.

There is potential to include other variables that can be measured from space, subject to their maturity for inclusion in a sustained ocean observing system. For example, work has been done on the four years of available salinity data from the NASA Aquarius mission (2011-15). To some extent this will evolve naturally as new missions become multi-variable.

With respect to sea ice, feedback from users and stakeholders indicates an appetite to begin engaging with IMOS in satellite remote sensing, to complement *in situ* ocean-ice zone observing planned through Argo and satellite animal tracking. This would present an exciting opportunity if sufficient resources were available.

In summary, continued investment by IMOS in Satellite SST and Altimetry calibration/validation/collection, and data processing/management/products, is warranted. There is potential to enhance Altimetry calibration and validation to fully exploit the SWOT mission launched in 2020. Continued investment in OCR is warranted at some level, including the national Bio-Optical Database and national data processing/management/product delivery. The exact nature of IMOS investment on OCR calibration and validation requires further consideration, including recommendations from the IMOS OCR Task Team, and international interest in developing a 'bluewater' OCR calibration and

validation site off Perth. Opportunities to begin working with the sea ice community in the ice zone will be explored.

**Wave measurements** arise as a major gap in many fora involving IMOS. The need for a more national approach to wave measurements gained momentum at the inaugural Australian [Forum for Operational Oceanography](#) (FOO) in July 2015, and IMOS has subsequently supported a FOO Working Group on surface waves (and another on surface currents). Given the clear imperative in the Innovation Agenda to drive collaboration between researchers, government and industry to deliver practical outcomes, FOO has rapidly become an important stakeholder for IMOS.

The FOO surface waves working group has enabled development of credible proposals for IMOS to begin investing in calibration, collection and distribution of ocean surface wave data from current and next generation satellites, with the potential for investment in related *in situ* measurements - possibly directional wave buoys and/or unmanned surface vehicles, along with consideration of the utility of data from the existing IMOS Ocean Radar network, National Mooring network, and data from operational wave buoys (both government agency and private sector). Enhancement of IMOS to include wave measurements is considered to be well-justified.

### Response to Drivers and Feedbacks

Collectively this portfolio of Broadscale Facilities will address the full suite of drivers to which IMOS needs to respond. Multiple pathways to uptake and impact are in place as outlined below, and these will provide many opportunities for co-investment.

<p><b>Basic research and research training</b></p>	<ul style="list-style-type: none"> <li>• Australian Antarctic Science Program, being reviewed and extended under the Australian Antarctic Strategy and 20 Year Action Plan</li> <li>• Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), and Australian Research Council (ARC) Antarctic Gateway Strategic Partnership</li> <li>• Numerous ARC funded research projects, including the ARC Centre of Excellence for Climate System Science</li> <li>• Contributing to and benefiting from basin scale ocean observing programs in the Southern, Indian, and Pacific Oceans</li> <li>• Global climate modelling (e.g. the Australian Community Climate and Earth-System Simulator, ACCESS) and climate change projections</li> <li>• State of Climate reporting, including the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 (AR6)</li> <li>• Contributing to and benefiting from global ocean databases (e.g. World Ocean Database)</li> <li>• Contributing to and benefiting from global ocean products (e.g. Surface Ocean CO<sub>2</sub> Atlas (SOCAT))</li> <li>• Participation in international, collaborative projects in the Australian region (e.g. Mesopelagic Southern Ocean Prey and Predators/MESOPP)</li> <li>• Multiple regional modelling activities in universities, PFRAs, operational agencies, and consulting industry</li> </ul>
<p><b>Applied and mission directed research</b></p>	<ul style="list-style-type: none"> <li>• Seasonal forecasting and prediction by the Bureau of Meteorology</li> <li>• National Environmental Science Program (NESP) Earth Systems and Climate Change Hub</li> <li>• National Environmental Science Program (NESP) Marine Biodiversity Hub</li> <li>• State of (Marine) Environment reporting (national, and regional e.g. GBR Outlooks)</li> </ul>

	<ul style="list-style-type: none"> <li>• Reef Integrated Monitoring and Reporting Program (RIMREP), in the context of the Reef 2050 Long Term Sustainability Plan</li> <li>• Great Australian Bight Research Program</li> <li>• Western Australian Marine Science Institution (WAMSI), in the context of the WA Marine Science Blueprint 2050</li> </ul>
<b>Research with operational relevance</b>	<ul style="list-style-type: none"> <li>• Ocean forecasting for the Department of Defence through the Marine Service Agreement with Bureau of Meteorology and CSIRO through Bluelink</li> <li>• Tailored marine products produced by the Bureau of Meteorology (e.g. for the GBR, ReefTemp and the Marine Water Quality Dashboard)</li> <li>• Value added products developed by the private sector (e.g. Fishtrack)</li> </ul>

Feedbacks will be addressed as follows.

**Deferred capital replacement** is not a major issue for Broadscale Facilities given extensive use of expendable equipment (Argo floats, satellite tags etc.). Some **future flexibility** will be required with respect to potential for enhancement around future satellite missions.

In terms of **readiness**:

- Pilot activity in ice-capable Argo to be reviewed and built into the ongoing program as appropriate.
- IMOS will work with the Bureau of Meteorology and the Department of Defence with respect to co-investment in recognition of the operational utility of mature aspects of Argo (core mission) and Ships of Opportunity (physics and biogeochemistry).
- Pilots in measuring biology and ecosystem variables from Ships of Opportunity will need to be matured.
- Pilots in Ocean Colour validation will be reviewed and evolved, or discontinued.
- Following successful proof-of-concept activities, new pilots should be commenced in Bio-Argo and Deep Argo.
- A new pilot will be considered in wave measurements.

All of the Broadscale Facilities are fairly **cost effective**, particularly when the leverage provided by international collaboration is taken into account. This is particularly true for satellite remote sensing and Argo.

**Key dependencies:**

- Access to data from foreign satellite missions is on track. With respect to the Sentinel missions, thanks go to Geoscience Australia (GA), CSIRO and Bureau of Meteorology (BOM) for negotiating an Australian 'Copernicus' Data Hub.
- Continued access to commercial vessels as Ships of Opportunity will remain an issue to be managed, as will vessels to deploy Argo floats in remote regions. These are not new issues.
- This portfolio of Broadscale facilities is expected to facilitate very strong engagement with the coastal and ocean modelling communities.
- During user and stakeholder feedback, it was noted that engagement between IMOS and the Australian global ocean modelling community was perhaps more indirect than it could be. Ocean-sea ice modelling was identified as one potential area for more direct engagement. The 2016 Australian Coastal and Oceans Modelling and Observations ([ACOMO](#)) Workshop presents an opportunity to explore this further.

## 3.2 Backbone

### Summary

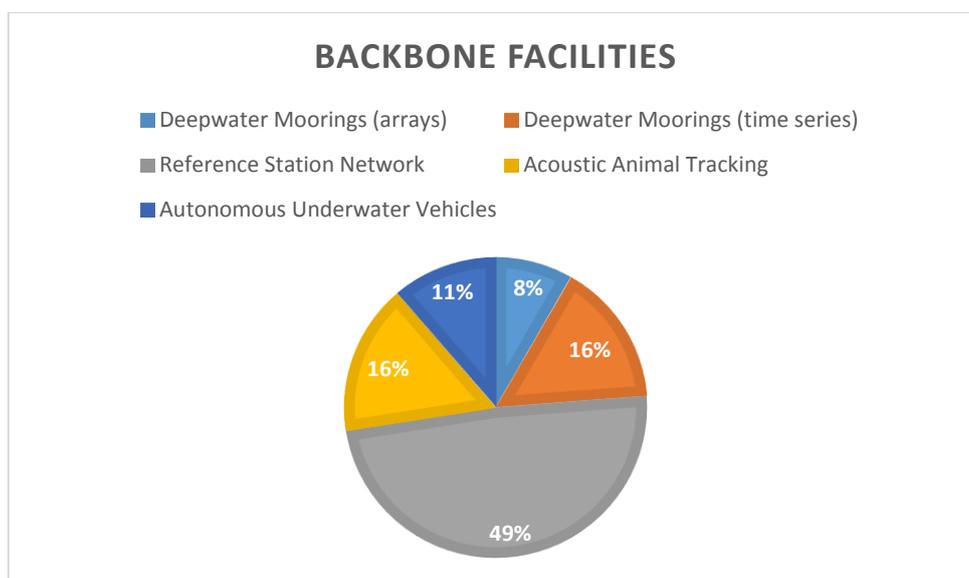
Backbone Facilities address two priority areas for IMOS. Firstly, in monitoring the major boundary currents and ocean-atmosphere processes that play a key role in connecting the broadscale and the regional. Secondly, in providing an integrated suite of national facilities to study marine biology and ecosystems, and their interaction with biogeochemical and physical processes. Emphasising biology and ecosystems in the Backbone is a strategic choice. It is based on an assessment that IMOS will make a much greater difference in sustained ecological observing by playing the role of national integrator and aggregator, guided by priorities around bioregional planning and management, assessing the state of the marine environment, and managing long ranging, cross-jurisdiction species (commercially exploited and threatened/protected).

The Backbone portfolio currently includes:

- Deepwater Moorings (transport arrays)
- Deepwater Moorings (time series)
- National Reference Station Network (including ocean acidification and passive acoustics)
- Acoustic Animal Tracking,
- Autonomous Underwater Vehicles (AUV).

All of these facilities warrant focused continuation, noting various issues raised in the Detailed Analysis that follows.

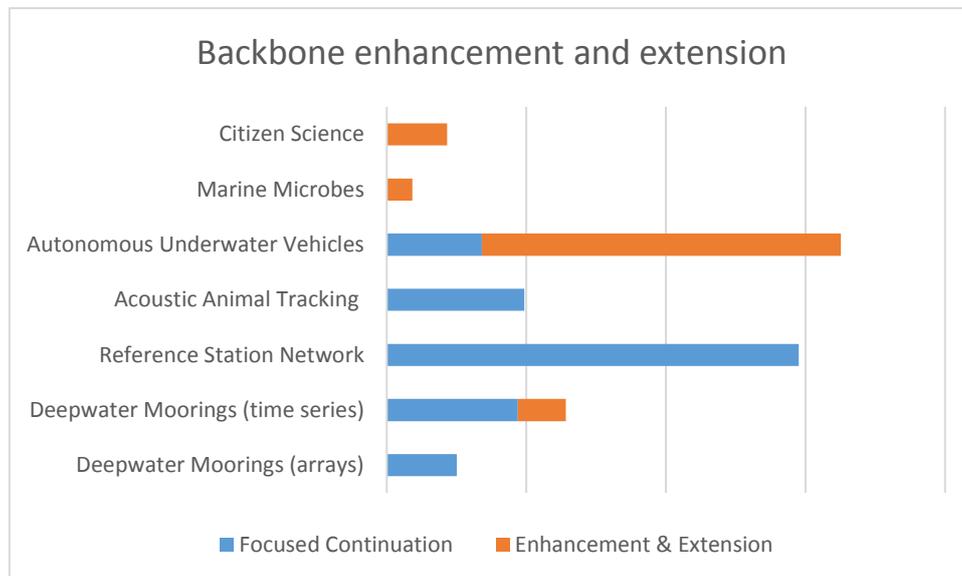
Relative distribution of resources required for focused continuation is shown below.



There is also potential to enhance and extend the Backbone portfolio in response to drivers and feedbacks. Proposed priorities are summarised below, and elaborated in the Detailed Analysis:

5. Extend Deepwater time series for improved seasonal climate prediction.
6. Enhance the AUV fleet with new vehicles and image handling capability, with a related enhancement of IMOS in citizen science.
7. Enhance IMOS to invest in the measurement of marine microbes, subject to assessment of technical readiness.

An indicative level of relative resources required for enhancement and extension is shown below. Enhancement and extension is shown in orange bars, relative to focused continuation in blue bars (which correlate with the pie chart above).



## Detailed Analysis

**Deepwater Moorings** are used in two configurations in IMOS – as transport arrays, and as time series sites.

As an island nation, Australia’s climate and coastal environment is strongly controlled by the complex network of currents in the surrounding ocean. Australia lies at an oceanic ‘crossroad’ of currents that provide the primary means for exchange between the ocean basins and therefore have a large influence on global ocean circulation and climate. This makes monitoring of major boundary currents a nationally and globally significant activity for IMOS, with emphasis on the Indonesian Through Flow (ITF) to the north, the East Australian Current (EAC), and the Leeuwin Current in the west.

Transport arrays can provide a viable means of monitoring the full depth transport of boundary currents where they are narrow and most coherent. Within IMOS, priority has been given to deploying transport arrays to measure the ITF (since June 2011) and the EAC (since April 2012). This work is critically dependent on access to the Marine National Facility (MNF) vessel *RV Investigator*.

Whilst both of these activities remain of high national and global priority, Australia has had difficulty gaining permission from Timor-Leste for the vessel access required to monitor the ITF. As a result, the ITF moorings were recovered and the monitoring program suspended in October 2015. The ~five years of data collected are already proving to be highly valuable, and we will continue to work with the international community to look for ways to measure this limb of the global ocean circulation.

IMOS will therefore focus on continuation of the EAC work, and the required vessel time has been secured in the MNF forward schedule.

There is scientific interest trying to measure Indian Ocean overturning circulation (in collaboration with scientists working off eastern South Africa) by enhancing the shelf mooring array off Perth to fully capture the Leeuwin Current. However the scientific feasibility of this proposal is yet to be determined.

Deepwater moorings can also be used to develop time series, providing the means to obtain high temporal resolution observations of physical, chemical and biogeochemical parameters, at a range of depths, and in regions where vessel availability is infrequent. The Southern Ocean Time Series (SOTS) Observatory includes three components – an air-sea flux mooring measuring real-time meteorological and oceanographic conditions at the sea surface, a biogeochemical mooring measuring carbon cycling and controls on marine productivity, and a deep ocean sediment trap mooring. SOTS represents an Australian contribution to the international [OceanSITES](#) global network of time series observatories, and is one of very few comprehensive sites in the Southern Ocean. The Southern Ocean is responsible for ~40% of the total global ocean uptake of human-induced CO<sub>2</sub> emissions, and 75% of the additional heat that these emissions have trapped on Earth.

Continued investment in SOTS is warranted, and the required vessel time has been secured in the MNF forward schedule.

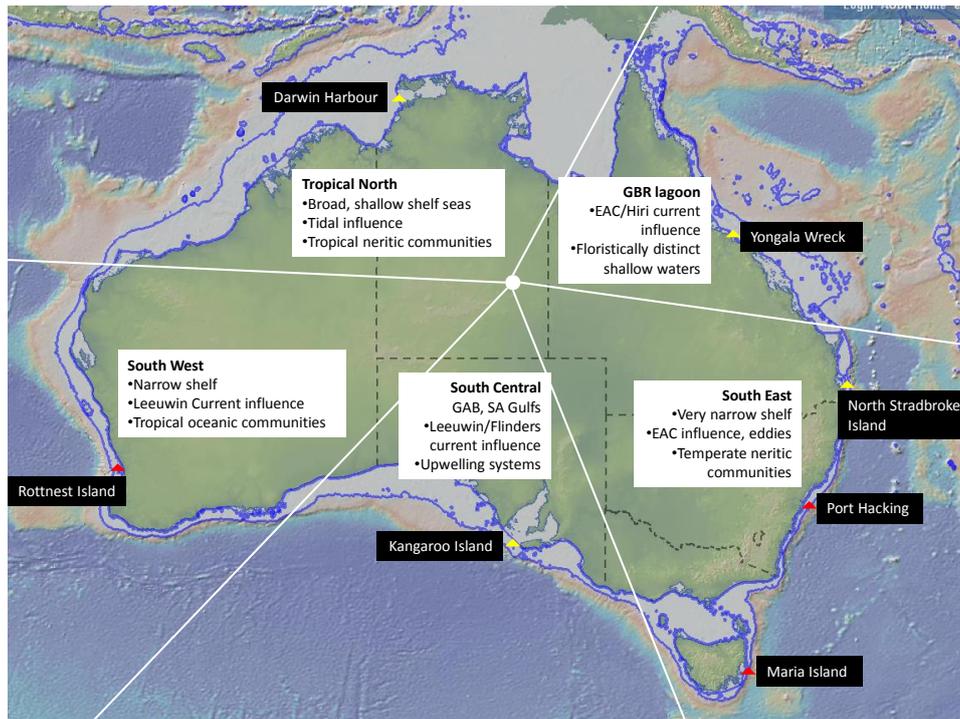
There is potential to extend the Deepwater Mooring time series to include measurement of tropical fluxes (at ~15S, 110E). These measurements would improve understanding of climate variability and improve predictions on intra-seasonal to three-month time scales. This could spin up in years three to five of the planning period, and could piggyback on tsunami warning system maintenance voyages. Vessel access and availability would in turn inform choice of technology and platform.

IMOS has piloted the implementation of a continental scale **National Reference Station (NRS) Network** designed to provide baseline information that is required to understand how large-scale, long-term change and variability in the global ocean are affecting the ecosystems of Australia's coastal seas. The goal is to develop multi-decadal time series of the physical and biogeochemical properties of Australia's coastal seas, to inform research into ocean change, climate variability, ocean circulation and ecosystem responses. Before IMOS was established, Australia had a general lack of long time-series against which more spatially replicated short term studies can be referenced. This was in large part due to the size of our ocean territory and extensive continental coastline, and the lack of a central coordinating mechanism.

The NRS Network currently consists of three established, long term sites (Maria Island, Port Hacking and Rottneest Island), three additional sites to adequately cover the distinct regions of Australia's coastal oceans (Darwin, Yongala and Kangaroo Island), and enhanced regional coverage in the EAC (North Stradbroke Island). The NRS Network sites currently include both continuous moored-sensor sampling, and monthly/quasi-monthly vessel-based sampling. They measure a wide range of physical, biogeochemical and biological variables. The NRS Network is a cornerstone of IMOS, embodying both the 'national' and 'integrated' perspectives that IMOS has aspired to bring to marine observing in the Australian region. It is also a very large Facility, comprising ~50% of investment in the national 'Backbone'. Much has been learnt through the process of establishing, growing, consolidating, and rationalising the NRS Network as IMOS has moved through its phases of development over the last decade. This experience will now be used to evolve the NRS Network towards those aspects that have been most productive, and/or those that have greatest potential for future impact.

Continued investment by IMOS in a National Reference Station Network is warranted on the following basis:

- The NRS Network needs to cover the five distinct regions of Australia's coastal oceans outlined in its (published and peer reviewed) Rationale, Design and Implementation Plan (see diagram below).



- Time series at the three very long running sites need to be continued above all else i.e. Port Hacking, Maria Island, and Rottneest Island (red triangles in the above diagram).
- Noting that Port Hacking and Maria Island are both in the South East region, this suggests a minimum national network of at least six sites. There are currently seven sites (including a third South East site at North Stradbroke Island), with two other sites (at Ningaloo Reef and Esperance) having been decommissioned during the survival/rationalisation phase.
- All time series, and particularly the three very long running time series, need to be continuously updated, available, easy to plot and use. By 2022 we will have 80 years of data from Port Hacking, 78 years from Maria Island, and 71 years from Rottneest Island, plus 13-15 years from the other sites – an extraordinary resource for future generations of scientists, students, and other users and stakeholders.
- A key aspect of the NRS ‘pilot’ was national scale deployment of a standard, moored, multi-sensor instrument, with on-board processing and inbuilt bio-fouling controls. This national network of standard instruments has been taking *in situ* measurements of eight different physical and biogeochemical variables, at two discrete depths, in 60 sample/one minute ‘bursts’ every 15 minutes. This approach has been very successful in developing a national coastal mooring technical capability, building datasets of unprecedented temporal intensity for physical variables, and driving development of automated quality control. It has delivered very useful data for some biogeochemical variables once calibration and quality control issues were resolved. For other variables, data quality from the multi-sensor chosen almost ten years ago has been so surpassed by new sensors that the cost of further effort to quality control the NRS Network data is unlikely to be exceeded by the scientific benefit, and we will be better served by moving to current generation sensors.
- In summary, the moored-sensor component of the NRS Network will evolve to use a small, nationally-agreed suite of instruments best suited to the variables of interest i.e. multi-sensor where possible to reduce cost, but not at the expense of data quality. It will also be focused in sites where there is demonstrated uptake and clear future demand for the high temporal

resolution provided by moored sensors. In the next phase of IMOS, not all NRS Network sites may have moored sensors (see below).

- The foundations of the NRS Network actually lie in vessel-based sampling. This is what provides the very long running time series at Port Hacking, Maria Island, and Rottneest Island. Notwithstanding the fantastic advances that autonomous platforms and sensors are providing, there remains a fundamentally important role for vessel-based sampling enabling scientists and technicians to get onto the water, deploy additional equipment to provide distinctive datasets of high scientific value, and take water samples for use and reuse by a variety of marine science communities. For the phytoplankton, zooplankton, ichthyoplankton, and marine microbial communities, it is the NRS Network continental scale vessel-based sampling and its rich environmental context that is proving to be most useful. There is further potential to leverage the network to investigate emerging issues, such as micro-plastics.
- In summary, future IMOS investment in the NRS Network will be defined by the vessel-based sampling component and augmented by the moored-sensor component i.e. IMOS may have NRS sites without moored-sensor packages. Vessel-based sampling protocols will be evolved to ensure maximum utility for the phytoplankton, zooplankton, ichthyoplankton, and marine microbial communities, as well as the overlapping interests of the Ocean Colour satellite remote sensing community. Utility for research into micro-plastics will be investigated.
- Across the NRS Network (vessel-based and moored-sensor), IMOS will focus on standard approaches to instrument calibration, data quality control (by variable), and uptake of data (via models, analyses and products).
- Opportunities to grow the network 'inshore' will be explored. It is conceivable that long term sampling programs run by partner organisations could be turned into a coastal NRS network by implementing standard sampling procedures and data management practices for an agreed suite of essential ocean variables. Marine biosecurity is one driver for such a development.

Augmenting the NRS Network sampling program, ocean acidification moorings have been deployed at three sites (Maria Island, Yongala, and Kangaroo Island) to cover both tropical and southern temperate waters. For various reasons, a fourth site at Heron Island which pre-dated IMOS has subsequently been brought into the network and Yongala has been paused. These moorings measure CO<sub>2</sub> and pH at high precision and in near real time. They conform with international standards and form part of the Global Ocean Acidification Observing Network ([GOA-ON](#)). Providing sustained observations to inform ocean acidification research remains a priority for IMOS. In the next phase, increased emphasis will be placed on bringing the carbon chemistry together with information on biological responses. The integrated nature of IMOS means that we are distinctively placed to support whole of system approaches at the leading edge internationally, in both the iconic Great Barrier Reef region, and in southeast Australia where ocean acidification is of increasing concern to valuable fishing and aquaculture industries.

The final component considered here is the acoustic observatories network. 'Passive' acoustic observatories record sound emitted by natural processes in the ocean, underwater noise sources of biological origin, such as marine mammals, crustaceans or fish, plus man-made noise sources. Through analysis of these signals it is possible to discriminate and identify different animal species and to assess the number of animals present within the range of acoustic observation, which can then be linked to ocean productivity or yearly migratory passage for great whales. Good progress has been made in collection and publication of data, but there is not yet broad utilisation of the dataset. It is highly specialised, and plans are underway to enable users to identify species of interest using standard algorithms. There is also unrealised potential for collaboration in the Southern Ocean and Antarctic where passive acoustics is used to monitor marine mammals, ice, and

anthropogenic noise. In summary, continued investment by IMOS in a coordinated acoustic observatories network has the potential to produce a dataset of national and global significance, particularly as the issue of ocean noise becomes higher profile in the sustainable management of oceans globally.

**Marine Microbes** play a critical role in our ocean's health. Making up the bulk of ocean biomass they directly control the majority of the oceans energy production and are ultimately responsible for regulating the marine food-web. However, little is known about the dynamic nature of these organisms. As noted above, the marine microbial community has been using the NRS Network vessel-based sampling program for some time. This commenced with the Australian Marine Microbial Biodiversity Initiative, using water samples from all NRS Network sites to begin characterising the Australian marine microbial biome for the first time. Early success led to a more recent Marine Microbes Project with Bioplatforms Australia, another NCRIS capability. This project includes both a pelagic component supported by NRS Network sampling, and a benthic/coastal component also of strategic interest to IMOS in terms of expansion into shallower waters.

As marine microbial science progresses we need to find faster, cheaper, more efficient ways to go from water sample to sequence to bioinformatic analysis to useful information in the hands of researchers, environmental managers and marine industry managers concerned with ocean health, including Harmful Algal Blooms (HABs) and marine biosecurity. Development of remotely deployable, autonomous instrumentation for *in situ* microbial sensing is developing rapidly. While still considered at proof-of-concept stage in mid-2016, it is plausible that this instrumentation will be ready for pilot scale deployment in the latter stages of the IMOS Five Year Planning period. The potential to enhance IMOS to include an *in situ* microbial sensing component in years three to five should be considered, subject to careful evaluation of technology readiness.

IMOS has also piloted the implementation of a continental scale **Acoustic Animal Tracking** network. Acoustic tracking can be applied to fish species and other marine taxa such as crustaceans, marine reptiles, and marine mammals. It can be used for determining movement and location, intra-specific behaviours such as schooling, timing and duration of spawning aggregations, timing and duration of mating pair formation, timing and frequency of predator-prey interactions, and dynamics of mixed species aggregations. Acoustic data provide an understanding of the distance and speed at which migratory species travel, whether environmental factors affect their migratory instincts, and the sort of habitats selected by species for stopping over. This information leads to better management of Australia's fisheries, resources and marine protected areas.

Getting the IMOS national Acoustic Tracking network to reach its potential has been quite challenging for a range of reasons. It required the formation of a leadership group across institutions and jurisdictions, and development of a national database as a repository and storage facility. Specific data policies then had to be developed in order to get the animal tracking community comfortable with the idea of open data access and, uniquely within IMOS, we have allowed embargoing of data (largely for student projects) and in rare circumstances protection of data (largely for white sharks). All of this has required high levels of cooperation between IMOS (Animal Tracking and AODN Facilities), tag owners, operators of other receiver networks contributing data, and international collaborators at the global Ocean Tracking Network ([OTN](#)) in Canada and IOOS Animal Telemetry Network ([ATN](#)) in the USA.

As of June 2016, we now have an impressive national scale acoustic tracking capability in place. There are many IMOS-funded receivers in the water, many partners contributing extra receivers/detections, and national database that is recognised as world leading. There has been a paradigm-shift towards open access to biological data, with 34 million species detections openly accessible and

a further 17 million soon to become un-embargoed. Some 125 species have been detected, and the power of a national network is being demonstrated through new discoveries about animal behaviour that would not have been possible without a joined-up national network to detect them.

To get to this stage it has been necessary to build the network ‘bottom up’, and the next step is to have users and stakeholders provide more ‘top down’ input into a national network design. Discussions have commenced with the Research Providers Network (RPN) of the National Fisheries and Aquaculture Research Development & Extension Strategy, the NESP Marine Biodiversity Hub, and the Species Conservation Section of the Australian Government Department of the Environment. The intention is to identify a fairly short list of priority species for which acoustic tracking is an appropriate research tool and ensure that the national network is configured in a way that will provide the required information for these species, noting that many others will be detected and recorded in the national database for use and reuse.

In summary, continued investment by IMOS in a nationally coordinated acoustic Animal Tracking network is warranted.

The **Autonomous Underwater Vehicle (AUV)** Facility provides precisely navigated time series measurements of benthic imagery at selected locations on Australia’s continental shelf. While very large-scale surface processes can be addressed adequately by remote sensing and ship-borne systems, characterisation of many marine processes requires the ability to sense at high resolution in close proximity to the seafloor. The ability to conduct geo-referenced, high resolution, repeatable surveys of marine habitats – particularly those beyond diver depths – represents one of the major benefits of AUVs.

IMOS is undertaking arguably the world’s first benthic observing program to make extensive use of AUVs for the purpose of monitoring benthic habitats on such a large scale. The surveys are broadly divided into temperate and tropical reef environments and span the entire latitudinal range of the Australian continent. The IMOS integrated benthic monitoring program has three objectives:

1. Long term monitoring of deepwater reefs (20-200m)
2. Long term monitoring of the density and distribution of kelp (*Ecklonia radiata*), and
3. Interpreting the dynamics of benthic reef systems in the context of biophysical coupling.

The program has recently been internally reviewed by the national experts involved, including representatives from the NESP Marine Biodiversity Hub and the ARC Centre of Excellence for Coral Reef Studies. The review makes several recommendations that will assist in improving the forward program. IMOS plans to continue investing in the AUV Facility to provide a nationally coordinated approach to integrated benthic monitoring, guided by the major research programs providing scientific advice to end users and stakeholders.

It needs to be recognised that the IMOS integrated benthic monitoring program has been implemented with one vehicle i.e. the ‘Sirius’ AUV managed by the University of Sydney’s Australian Centre for Field Robotics (ACFR), which is a modified version of a mid-size robotic vehicle called ‘Seabed’ built at the Woods Hole Oceanographic Institution in the USA.

Australia has the third largest ocean territory on the planet, and has created a large network of marine protected areas. It is therefore surprising that as a nation we are not making much greater use of autonomous marine systems, such as AUVs, to observe and monitor our vast and valuable marine estate. There is demonstrated need for greatly enhanced capability to support marine science for the planned development of northern Australia, management of Commonwealth Marine Reserves, and exploration of remote regions in Australia’s Exclusive Economic Zone (EEZ). This gap

was recognised during development of the National Marine Science Plan (2015-25), and a working group has been formed to create a [National Marine Technology Roadmap](#) in response.

There is potential to enhance IMOS to include additional vehicles and expanded capabilities in the AUV Facility.

This could involve acquiring new vehicles through current and/or new partners. In addition to the established expertise of ACFR, organisations such as Deakin University, Queensland University of Technology, the Defence Science and Technology Group, AIMS, and CSIRO have existing and/or emerging capability in autonomous marine systems.

It could involve leveraging new capabilities coming on stream through related programs such as the Antarctic Gateway Partnership. For example, through 'Gateway' the Australian Maritime College (at UTAS) is in the process of establishing a new facility with an International Submarine Engineering (ISE) [Explorer AUV](#) to acquire high resolution data under sea ice and ice shelves. However this new, Australian Government funded vehicle will not spend all of its time under the ice, and could conceivably be deployed in other environments such as Commonwealth Marine Reserves. The Explorer will be able to reach depths of 5,000m whereas Sirius is limited to 700m depth. The commissioning phase for Explorer may present a unique opportunity in this respect.

There is also potential to expand our image processing capabilities. The IMOS AUV Facility delivers data products that are precisely georeferenced using state-of-the-art terrain-aided navigation algorithms, and optical imagery in the form of individual high resolution, colour corrected images (geotiffs), and processed as mosaics and 3D seafloor reconstructions. This is excellent capability, but only a small fraction of the resulting images has been annotated so that they can be turned into quantitative estimates such as abundance and cover of benthic organisms. Expanded image processing capability to remove bottlenecks would unlock this potential, and also have application for related technologies such as Baited Remote Underwater Videos (BRUVs) and photo quadrats from diver based surveys (see below).

In summary, significant enhancement of the AUV Facility, from single vehicle to 'national fleet', warrants serious consideration on a 2017-22 timeframe.

N.B. Despite being described as 'autonomous', the vehicles being considered here almost always require vessel support to operate in the marine environment. Plans to enhance this capability within IMOS will need to carefully consider the associated research vessel requirements - coastal, shelf, bluewater, and polar.

IMOS does not currently have any direct investment in **Citizen Science**, and this issue has been discussed at the Advisory Board level. The Australian Government is supportive of Citizen Science programs, both as a cost effective way to leverage its science and research investments, and also as a means to more directly engage the taxpaying public in the conduct of science and research in the national interest. The AUV Facility is one IMOS Facility that has reached into the domain of Citizen Science through the '[Explore the Seafloor](#)' project, and involving the general public in annotation may be one part of removing the bottlenecks outlined above. As a research infrastructure, IMOS will need to remain clearly focused on producing data of sufficient quality to be used in peer reviewed publications, and in analyses and products that will be used by managers and decision makers. Reef Life Survey ([RLS](#)) is a well-established, high profile, citizen science project that meets these criteria. IMOS and RLS have worked together to bring some RLS data into the AODN. There is potential to grow this relationship by bringing RLS more formally into the IMOS program, complementing the 'below diver depth capability' of our AUV Facility, working together on image processing and data

management, and better integrating IMOS physio-chemical data with RLS ecological data. In summary, there is clear potential for enhancement of IMOS to include a Citizen Science component.

## Response to Drivers and Feedbacks

Collectively this portfolio of Backbone Facilities will address a significant number of the drivers to which IMOS needs to respond. Multiple pathways to uptake and impact are in place as outlined below, and these will provide many opportunities for co-investment.

<p><b>Basic research and research training</b></p>	<ul style="list-style-type: none"> <li>• Australian Antarctic Science Program, being reviewed and extended under the Australian Antarctic Strategy and 20 Year Action Plan</li> <li>• Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), and ARC Antarctic Gateway Strategic Partnership</li> <li>• State of Climate reporting, including the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 (AR6)</li> <li>• Numerous Australian Research Council (ARC) funded research projects</li> <li>• Participation in international, collaborative projects in the Australian region (e.g. OceanSITES)</li> <li>• Contributing to and benefiting from global ocean products (e.g. Surface Ocean CO<sub>2</sub> Atlas (SOCAT))</li> <li>• Multiple regional modelling activities in universities, PFRAs, operational agencies, and consulting industry</li> <li>• Outputs have relevance for communicating science and conducting public outreach (e.g., public seminars, workshops, meetings, Science in Schools, media interviews) and for engagement of Non-Government Organisations (e.g. World Wide Fund for Nature) and community organisations (e.g. Recreational Fishing Trust)</li> </ul>
<p><b>Applied and mission directed research</b></p>	<ul style="list-style-type: none"> <li>• National Environmental Science Program (NESP) Earth Systems and Climate Change Hub</li> <li>• Seasonal forecasting and prediction by the Bureau of Meteorology</li> <li>• NESP Marine Biodiversity Hub</li> <li>• NESP Tropical Water Quality Hub</li> <li>• State of (Marine) Environment monitoring and reporting (national, and regional e.g. GBR Outlooks, Spencer Gulf Aquaculture Environmental Monitoring Program)</li> <li>• Commonwealth Environment Departments (e.g. Department of the Environment, Great Barrier Reef Marine Park Authority (GBRMPA)) for assessing management, mitigation and adaptation options to offset the impact of environmental change on ecosystems and manage threatened species.</li> <li>• Fisheries management agencies (e.g. Australian Fisheries Management Authority) and the Fisheries Research &amp; Development Corporation (FRDC)</li> <li>• Reef Integrated Monitoring and Reporting Program (RIMReP), in the context of the Reef 2050 Long Term Sustainability Plan</li> <li>• Great Australian Bight Research Program</li> <li>• Western Australian Marine Science Institution (WAMSI), in the context of the WA Marine Science Blueprint 2050</li> <li>• Darwin Harbour Water Quality Protection Plan (WQPP) NT Government Department of Land Resource Management</li> </ul>

<b>Research with operational relevance</b>	<ul style="list-style-type: none"> <li>• Ocean forecasting for the Department of Defence through the Marine Service Agreement with Bureau of Meteorology and CSIRO (Bluelink)</li> <li>• Tailored marine products produced by the Bureau of Meteorology (e.g. for the GBR, ReefTemp and the Marine Water Quality Dashboard)</li> <li>• eReefs modelling and remote sensing</li> </ul>
--	---

Feedbacks will be addressed as follows.

**Deferred capital replacement** is an issue that will need to be managed for the National Reference Station Network Facility. **Future flexibility** will be required if we are to take up opportunities in Marine Microbes, and Deepwater Moorings for tropical fluxes in later years.

In terms of **readiness**:

- Emphasis will be placed on maturing the continental scale National Reference Station and Acoustic Animal Tracking networks.
- Specific attention needs to be paid to Ocean Acidification, bringing carbon chemistry and biological responses together.
- Specific attention also needs to be paid to broadening the utility of the Acoustic observatories network.
- New pilots will be considered in measuring tropical fluxes, enhancing the AUV Facility with additional vehicles and expanded image processing capability, and using Citizen Science to expand our ecological data holdings.
- Subject to successful proof-of-concept, a new pilot for *in situ* Marine Microbial observing will be considered in years three to five.

**Cost effectiveness** is most significantly an issue for the National Reference Station Network, and our focus on driving down the cost per observation will need to continue. Deepwater Moorings and AUVs are undeniably expensive items, but by focusing on science productivity and impact we can put this into a 'cost benefit' framework, and assess cost effectiveness in the context of what we are getting for our money. In both of these cases, recent performance assessments indicate a positive relationship between benefit and cost. Inclusion of a Citizen Science component would be a cost effective means of enhancing IMOS.

**Key dependencies:**

- The Deepwater Moorings facility has a critical dependency on the Marine National Facility. Vessel time for the two priorities (EAC and SOTS) has been secured in the MNF forward schedule.
- Engagement with the climate, oceanographic and atmospheric modelling communities will be facilitated by the crucial measurements provided through the Deepwater Moorings Facility. Engaging with biological and ecosystem modelling communities in use of observations and data from the National Reference Station Network, Animal Tracking Network, and Integrated Benthic Monitoring Program/AUV Facility will be more challenging, requiring dedicated focus and effort. The 2016 Australian Coastal and Oceans Modelling and Observations ([ACOMO](#)) Workshop is being designed with this opportunity in mind.

### 3.3 Regional

#### Summary

It is important to note that in the context of the Five Year Plan, IMOS will not invest in region-specific 'Facilities'. We will invest in National Facilities responding to the needs of multiple Regions. Relative effort of these National Facilities across Regions will be prioritised based on strength of connection to regional modelling efforts (physical, BGC, ecosystem), and potential to engage with the development of operational oceanography in Australia. This is key in terms of response to the National Innovation and Science Agenda, and the National Marine Science Plan (with its focus on driving development of Australia's blue economy). It is expected that strong support from Regional stakeholders and users will manifest in commitments to co-invest. Identification of opportunities to drive efficiencies across Facilities and work more collaboratively with others operating marine infrastructure will also be investigated.

The Regional portfolio currently includes:

- Ocean Gliders
- Ocean Radar
- Moorings Network (continental shelf and coastal)
- Wireless Sensor Network (GBR), and
- Satellite Animal Tracking.

Moorings, gliders and radars provide the bulk of the IMOS regional capability (94%) and warrant focused continuation.

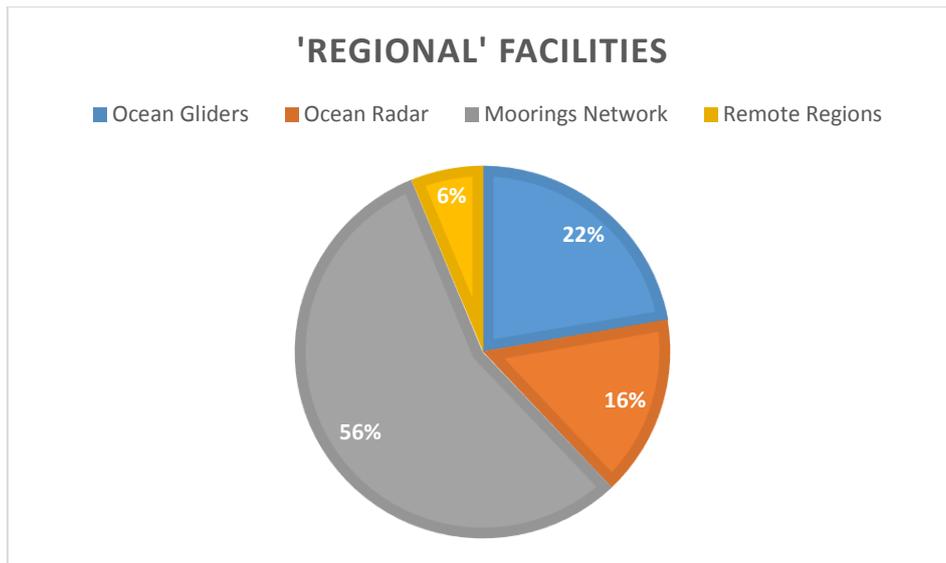
The GBR **Wireless Sensor Network** was an ambitious pilot project to develop a 'digital skin' for the GBR. It has been successful at the technical level, but has not been taken up by the coral reef science community at anywhere near the level anticipated. This pilot will be wound back to a base level of infrastructure at the research intensive island research stations where it has proven utility, and the technological developments will be reused within other Facilities where possible.

**Satellite Animal Tracking** is used successfully at Broadscale in the Southern Ocean. IMOS has piloted this technology at Regional scale, with tagged Sea Lions in the Great Australian Bight. The pilot has been successful in terms of building a useful dataset, but we have not seen strong uptake by the regional modelling community and certainly no preference for these regional scale observations over moorings, radars, and gliders. There is interest by the animal tracking community in extending this pilot into other regions (southwest WA and Bass Strait). However the overall strategy of IMOS in animal tracking is to take a national, not a 'sum of regions' approach (see Backbone section). One of the main arguments for using Satellite Animal Tracking is that the animals can allow us to obtain observations from regions that are otherwise difficult or expensive to obtain.

Other technologies are being proposed for use in remote regions. These include Surface Drifters, and the Australian Maritime Safety Authority (AMSA) has expressed interest in closer collaboration with IMOS around operational surface drifter deployments and drift modelling. Looking ahead, drones and other autonomous technologies may come into play.

Based on the above, IMOS will consolidate its current investments in Wireless Sensor Networks and Satellite Animal Tracking into an investment in observing **Remote Regions** which will then be considered for enhancement and extension using the technologies most fit for purpose.

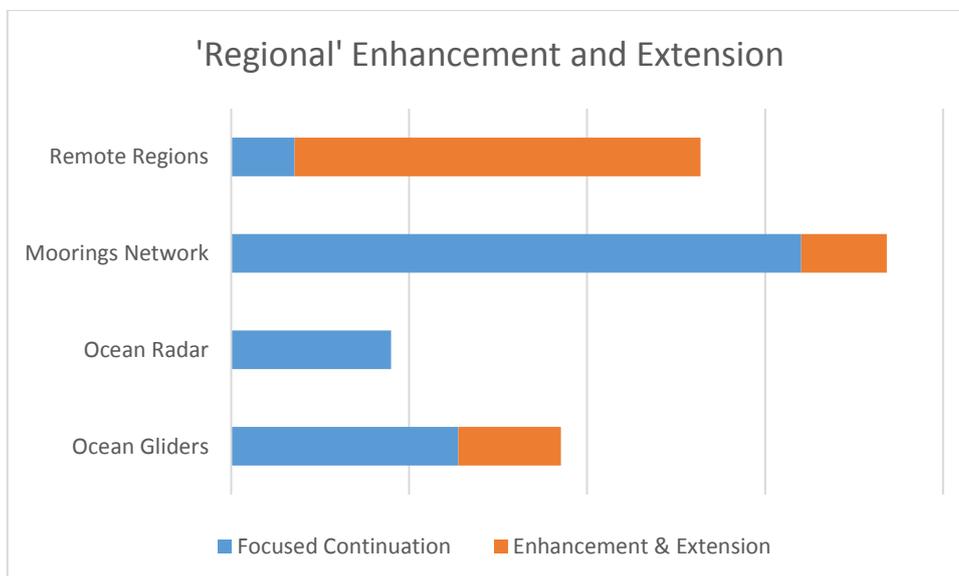
Relative distribution of resources required for focused continuation is shown below, noting various issues raised in the Detailed Analysis that follows.



There is also potential to enhance and extend the Regional portfolio in response to drivers and feedbacks. Proposed priorities are summarised below, and elaborated in the Detailed Analysis:

8. Extend Ocean Glider activity in the East Australian Current, and the continental shelves of NSW and WA (where use of gliders is most mature).
9. Extend the Moorings Network in the northern GBR, and Bonney Upwelling/Bass Strait.
10. Enhance IMOS with additional capability to monitor in Remote Regions.

An indicative level of relative resources required for enhancement and extension is shown below. Enhancement and extension is shown in orange bars, relative to focused continuation in blue bars (which correlate with the pie chart above).



Noting that ongoing co-investment is essential to the functioning of IMOS as a whole, our ability to undertake Regional enhancements and extensions is likely to be particularly dependent on the ability of Regional partners to co-invest in the national research infrastructure. This should be attractive given the leverage provided, and the fact that the incremental cost of adding to a functioning national system (with a track record in reliable data access) is much lower than going it alone, region by region.

## Detailed Analysis

The **Ocean Glider** Facility operates a fleet of autonomous underwater ocean gliders that undertake measurements of shelf and boundary currents in Australian waters. As traditional ship-based oceanographic observations are expensive and time consuming, the development of autonomous ocean gliders to sample the marine environment represents a technological revolution for oceanography. The gliders are relatively cheap, reusable and can be remotely controlled, making them a cost-effective platform for collecting repeat subsurface ocean observations. They also allow for the acquisition of data under inclement weather conditions. Equipped with a variety of sensors which go beyond physics and into biogeochemistry, gliders are designed to deliver ocean profile data at spatial and temporal intensity never before seen in Australian shelf and coastal waters.

Ocean Glider technology was not available to the Australian marine and climate science community before IMOS was established. IMOS has rapidly enabled the creation of a national facility with a substantial glider fleet which is in high demand. It is enabling new discoveries and contributing to an unprecedented level of sub-surface ocean profiles on the Australian continental shelf, which in turn is creating new opportunities for modelling, analysis and product development.

IMOS has piloted the use of two glider technologies. Slocum gliders, designed to operate in coastal waters of up to 200 m deep where high manoeuvrability is needed. And Seagliders, designed to operate in the open ocean in depth up to 1000m. For various reasons, the Slocum glider component has been far more successful and is now the dominant vehicle in the fleet.

IMOS plans to continue investing in an Ocean Glider Facility, with deployment priorities guided by the major regional modelling and analysis programs that have strong user bases and clear pathways to impact. This value chain is largely already in place across the five IMOS Regional Nodes, noting that there is a need to mature the use of gliders in some regions from a pilot mode of exploration and discovery, to a sustained observing mode of building datasets for use and reuse.

There is potential to extend the Ocean Glider Facility on the continental shelves of NSW and WA where the use of gliders is most mature. There is also an opportunity to concentrate the use of remaining Seaglider assets to conduct an experiment in measuring the EAC with gliders in conjunction with the Deepwater Mooring EAC transport array. The objective would be to understand what role gliders can play along with other technologies in cost effective monitoring of boundary currents. It would be a collaborative effort, involving University of Western Australia (UWA), CSIRO, University of New South Wales (UNSW), and possibly Scripps Institute of Oceanography and other international partners.

The use of gliders to support event-based sampling has also been proposed, in the tropical north. As a systematic and sustained marine observing system, IMOS needs to carefully consider network design and the necessity to build quality-controlled datasets and time series that can be used and reused. IMOS research infrastructure investment should not fund one-off process studies. That said, as we stretch towards a vision of sustained ecological observing, recognition of the timescales at which marine ecosystems actually respond will need to be taken into account. This may mean there is a place for event-based sampling within the IMOS portfolio when coupled with complementary techniques, such as satellite remote sensing and ocean modelling. Any strategy for event-based sampling will need to be developed from a national, rather than regional (e.g. tropical) perspective.

**Ocean Radar** provides maps of surface currents representative of the upper 1-2 m, covering mesoscale areas of coastal ocean (typically up to 150km x 150km), at unprecedented temporal and spatial resolution. Resolution can range from 5 minutes to 1 hour, and 1.5 to 5 km, respectively. In

some locations, significant wave height and wind direction can also be measured within 200km of the coast. Ocean Radar works by transmitting radar waves from land which are scattered by the rough sea surface.

Use of Ocean Radar is quite mature in some parts of the world, particularly the USA. Pre-IMOS its use was limited to one ARC-funded experimental installation on the southern GBR. Somewhat similar to Ocean Gliders, IMOS has rapidly enabled the creation of a national facility with sites in four of five Regional Nodes. Two technologies have been piloted – Phased Array (WERA) and Direction Finding (CODAR). CODAR is the dominant player in the USA and globally, though both technologies have relative strengths and weaknesses across variables measured. In general, WERA performs well when the surface current field is complex, with eddies, jets and fronts, and CODAR is particularly good for large-scale steady flows. Noting comments above about potential to measure wave height and wind direction, the IMOS Ocean Radar Facility was primarily tasked with the job of measuring surface currents.

There are six sites, each with two stations (required to turn radials into vectors) – southern GBR (WERA), Coffs Harbour in NSW (WERA), Bonney Coast (CODAR) and SA Gulfs (WERA) in SA, and Rottneest Shelf (WERA) and Turquoise Coast (CODAR) in WA.

It has taken some time to stabilise the Ocean Radar Facility. Challenges have included obtaining the required permits and permissions to install equipment in coastal regions. Eight of twelve IMOS stations are WERA technology which has a much larger spatial footprint on the coast. (The fact that CODAR has a much smaller footprint is a major reason why it has such market penetration globally.) Also, this Facility is now on its third Leader and second Operating Institution, and the level of turnover has inevitably caused some discontinuity. That said, as of June 2016 the Ocean Radar Facility is operating well and NSW State Government has recently co-invested in a seventh site at Stockton Bight (Newcastle) to observe the EAC separation zone. Potential for industry co-investment is also being discussed.

In summary, continued investment by IMOS in a national Ocean Radar network is warranted. Noting that uptake and use of data across the national network is much stronger in some regions than others, consideration will be given to relocating relatively underutilised assets, particularly if new partners are willing to assist in bearing the costs of relocation. There is also potential to increase the utility of the Ocean Radar network by placing greater emphasis on extraction of wave measurements (see Broadscale).

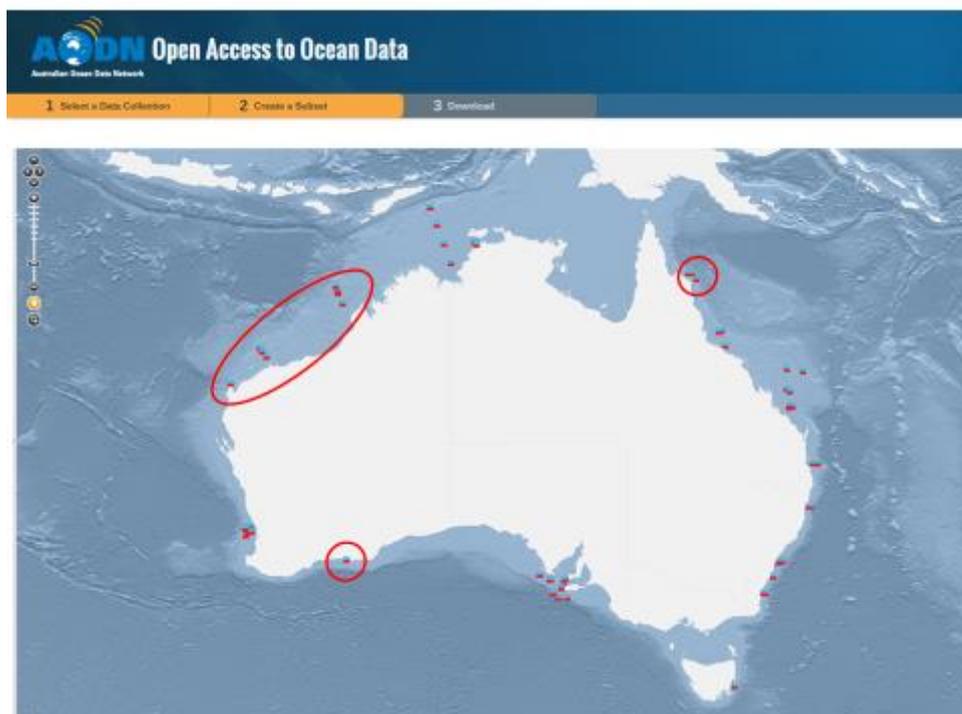
IMOS has piloted the implementation of a continental scale **Moorings Network** aimed at determining the fundamental physics of shelf and coastal ocean circulation, and the influence of climate and climate change. The primary method of uptake for Moorings Network data is through coastal and ocean model development and validation. This Facility is very closely related to the National Reference Station Network (see Backbone section), with common operating institutions, instrumentation, data handling, and in some cases, integrated design. However there are good reasons for considering them separately in the IMOS Five Year Planning process, particularly for the NRS Network and the relative priority of moored-sensor and vessel-based sampling (see above).

The main objective of the IMOS Moorings Network was to put in place a sustained observing capability that was simply lacking in Australia before IMOS was established. It is the largest IMOS Facility, comprising ~60% of investment in the national facilities delivering regionally. As IMOS has moved through its phases of establishing, growing, consolidating, and rationalising over the last decade, the Moorings Network has followed the same pattern. As of June 2016 it is well focused and the case for continuation is clear.

The Moorings Network is currently comprised of shelf and coastal moorings in the southern and central GBR, Joseph Bonaparte Gulf (NW WA/NT), off Perth (Two Rocks/Perth Canyon), GAB/SA Gulfs, and NSW shelf.

Noting that the primary method of uptake is through coastal and ocean modelling, the rapid development of modelling capability during the life of IMOS provides clear demonstration of the utility of the Moorings Network Facility (i.e. in the GBR, Darwin Harbour, NW WA and SW WA, GAB and SA Gulfs, and NSW shelf).

The figure below is a screenshot from the AODN, showing all historical Mooring Network and NRS Network locations for which we have data. The areas in red circles show where mooring assets have been completely removed through the survival/rationalisation phase i.e. northern GBR, NW WA (Kimberley/Pilbara shelf, and Ningaloo NRS), and western GAB (Esperance NRS). Moorings assets have also been ‘thinned’ in other regions.



In addition to NCRIS funding uncertainty, the Queensland and West Australian Governments co-invested cash to extend IMOS for periods of four to six years. When funding ceased, the Moorings Network (and other activities) had to be rationalised. This co-investment was valuable and all of the data collected remains accessible and reusable via the AODN. However for Facilities needing to be sustained over the very long term, this is perhaps not the best use of available co-investment.

IMOS plans to continue investing in a Moorings Network Facility at current scope and scale, with some redistribution of assets from Joseph Bonaparte Gulf to the Kimberley and Pilbara regions of NW WA. There is potential to extend the Moorings Network Facility to reoccupy the northern GBR (clearly a strategic gap given recent coral bleaching), and to monitor the Bonney upwelling region which is emerging as a ‘hot spot’ for various reasons. Maturing of pilot projects to deliver near real time data from moorings is also a priority, most likely requiring relocation of capability from where it could be developed, to where it will have most use and impact in the future.

As noted above, IMOS has piloted two Region-specific activities aimed at enabling cost effective data collection in **Remote Regions**. These will be wound back and future options considered in the context of all available technologies, noting the full suite of current IMOS capability and the

availability of new technologies. The cost of vessel support is a particular issue in Remote Regions, and IMOS needs to consider vessel-independent technologies that are fit for purpose.

The Node planning model tends to provide bottom up articulation of regional gaps according to geospatial coverage. Within the context of this Five Year Plan, IMOS will consider gaps in Remote Regions from the perspective of user and stakeholder needs, taking relevant drivers into account (e.g. White Paper on Developing Northern Australia, Defence White Paper, Reef 2050 Long Term Sustainability Plan, Commonwealth Marine Reserves, WA Marine Science Blueprint 2050).

Based on user and stakeholder feedback, the current investment envelope is unlikely to be anywhere near adequate for a meaningful response to identified needs. Significant enhancement of IMOS capability in Remote Regions warrants serious consideration on a 2017-22 timeframe.

### Response to Drivers and Feedbacks

Collectively this portfolio of ‘Regional’ Facilities will address a significant number of drivers to which IMOS needs to respond. Multiple pathways to uptake and impact are in place as outlined below, and these will provide many opportunities for co-investment.

<p><b>Basic research and research training</b></p>	<ul style="list-style-type: none"> <li>• Support of the 2<sup>nd</sup> International Indian Ocean Expedition (IIOE-2) 2015-2010 through IMOS observations in the Indian Ocean</li> <li>• Multiple regional modelling activities in universities, PFRAs, operational agencies, and consulting industry</li> <li>• Numerous Australian Research Council (ARC) funded research projects</li> <li>• Victorian Marine Science Consortium</li> <li>• Tasmania’s Sector Growth Strategies</li> </ul>
<p><b>Applied and mission directed research</b></p>	<ul style="list-style-type: none"> <li>• Seasonal forecasting and prediction by the Bureau of Meteorology</li> <li>• National Environmental Science Program (NESP) Marine Biodiversity Hub</li> <li>• National Environmental Science Program (NESP) Tropical Water Quality Hub</li> <li>• State of (Marine) Environment reporting (national, and regional e.g. GBR Outlooks)</li> <li>• Fisheries management state agencies and the Fisheries Research &amp; Development Corporation (FRDC)</li> <li>• Reef Integrated Monitoring and Reporting Program (RIMREP), in the context of the Reef 2050 Long Term Sustainability Plan</li> <li>• Queensland Ecosystem Health Monitoring Program (EHMP), Healthy Waterways, Queensland Departments of Science, Information Technology and Innovation (DSITI) and Environment and Heritage Protection (EHP), supported by southeast councils</li> <li>• Great Australian Bight Research Program</li> <li>• SA aquaculture industry and Spencer Gulf Environmental Development Initiative through Marine Innovation Southern Australia (MISA)</li> <li>• Western Australian Marine Science Institution (WAMSI), in the context of the WA Marine Science Blueprint 2050</li> <li>• Darwin Harbour Water Quality Protection Plan</li> <li>• Other state agencies such as NSW Office of Environment and Heritage, Maritime Safety Queensland (MSQ), Victorian Environmental Protection Authority (EPA), South Australian EPA.</li> <li>• NSW Marine Estate Management Authority (MEMA)</li> <li>• NSW Research Attraction &amp; Acceleration Program</li> </ul>

<b>Research with operational relevance</b>	<ul style="list-style-type: none"> <li>• Ocean forecasting for the Department of Defence through the Marine Service Agreement with Bureau of Meteorology and CSIRO (Bluelink)</li> <li>• Tailored marine products produced by the Bureau of Meteorology (e.g. for the GBR, ReefTemp and the Marine Water Quality Dashboard)</li> <li>• eReefs modelling and remote sensing</li> <li>• SA now-casts/forecasts from the eSAMarine project in collaboration with the BOM</li> <li>• eMAR Environmental Monitoring Assessment and Reporting in NSW through regional remote sensing validation (change in Chla)</li> <li>• Roads and Maritime, Ports - oil spill response</li> </ul>
--	---

Feedbacks will be addressed as follows.

**Deferred capital replacement** is an issue that will need to be managed for the Moorings Network and Ocean Glider Facilities. **Future flexibility** will be required if opportunities to address priority gaps in Remote Regions are to be taken up.

In terms of **readiness**:

- Emphasis will be placed on maturing the operation of Ocean Gliders and Ocean Radars, particularly in some regions.
- Pilots in GBR Wireless Sensor Networks and shelf scale Satellite Animal Tracking will be wound back. New pilots in cost effective monitoring of Remote Regions will be considered, subject to assessment of technical readiness.

**Cost effectiveness** remains an issue for the Moorings Network, and our focus on driving down the cost per observation will need to continue. Ocean Gliders and Ocean Radars are not low cost technologies, but rate well on a cost per observation basis relative to alternatives. Cost effectiveness is a rate limiting factor in Remote Regions, and IMOS will look to obtain as much design input as possible (e.g. from model experiments) before committing future investments.

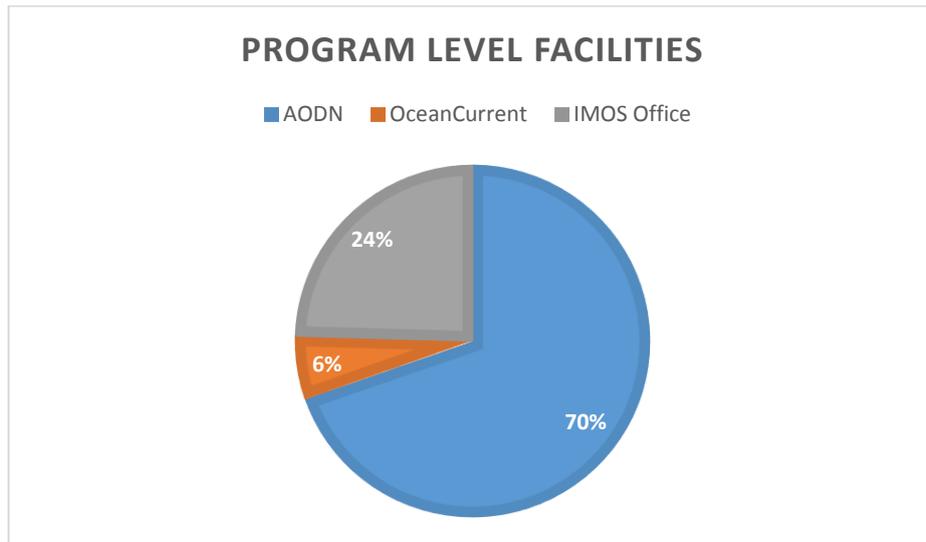
**Key dependencies:**

- The Moorings Network has a key dependency on the shelf and coastal vessel capability of partners, particularly AIMS in the tropical north and South Australian Research and Development Institute (SARDI) in the GAB. IMOS needs to strongly support planned replacement of shelf and coastal vessel capability, and addressing of gaps in the temperate south.
- This portfolio of 'Regional' facilities is expected to facilitate very strong engagement with the coastal and ocean modelling communities.

### 3.4 Program Level

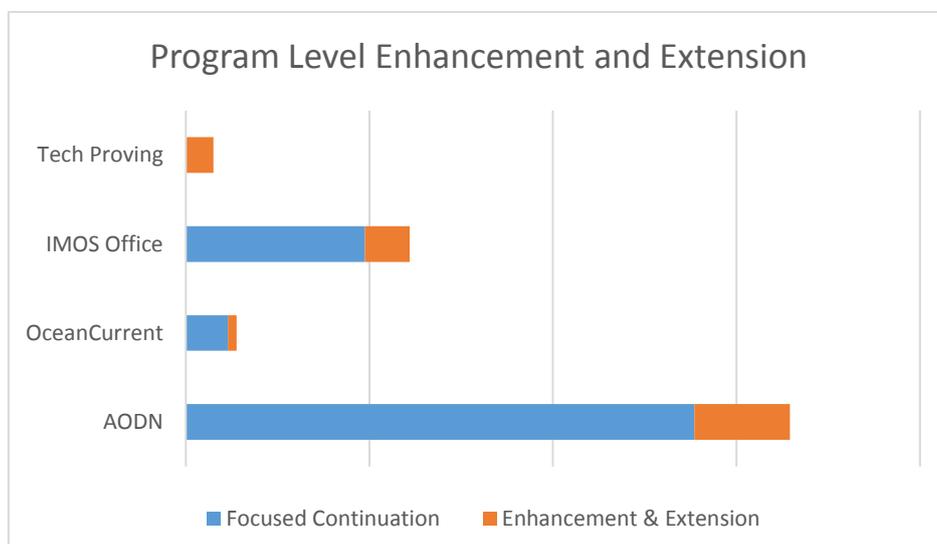
At the Program Level, we need to consider the IMOS Office, Australian Ocean Data Network (AODN), and IMOS *OceanCurrent*.

IMOS needs a properly resourced Office with an appropriate skill mix and a leadership succession plan. It also needs a properly resourced Australian Ocean Data Network (AODN) Facility, enabling open access to marine data beyond the IMOS data collections. *OceanCurrent* is highly valued by the IMOS community and a broader stakeholder base. It will be considered as a Program Level Facility consistent with our strategy to place increasing emphasis on the delivery of value added products. Relative distribution of resources required for focused continuation is shown below.



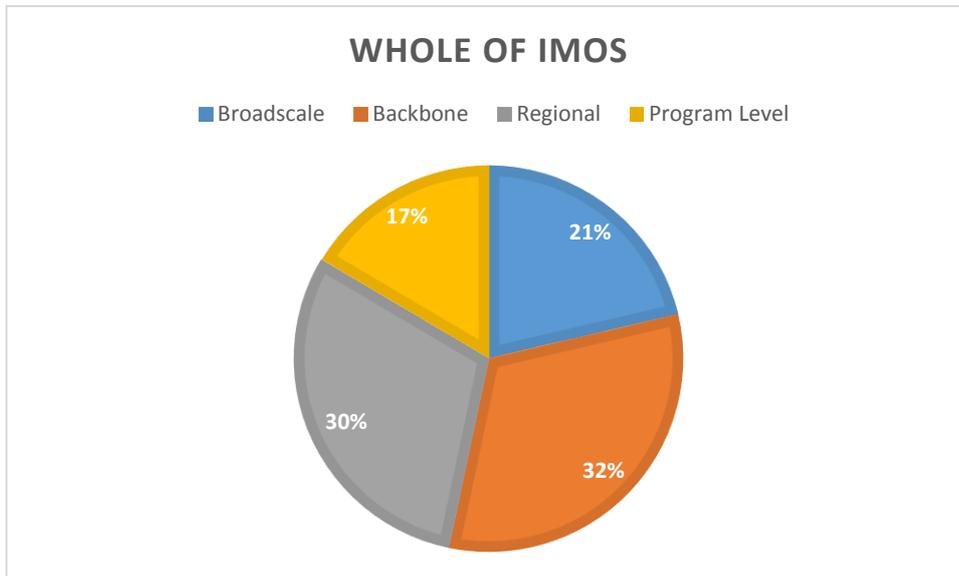
There is potential for modest enhancement at the Program Level. The IMOS Office is under resourced to handle the level of user and stakeholder engagement required in the current Node/Facility model. The AODN could be enhanced to accelerate availability of targeted datasets and to better embrace the data management expertise in partner organisations. As with the Satellite Remote Sensing Facility, *OceanCurrent* will need dedicated effort to exploit new satellite missions. There is also potential to create an explicit focus on proving new technologies at program level.

An indicative level of relative resources required for enhancement and extension is shown below. Enhancement and extension is shown in the orange bars, with focused continuation in blue bars.



## 4. Portfolio balance

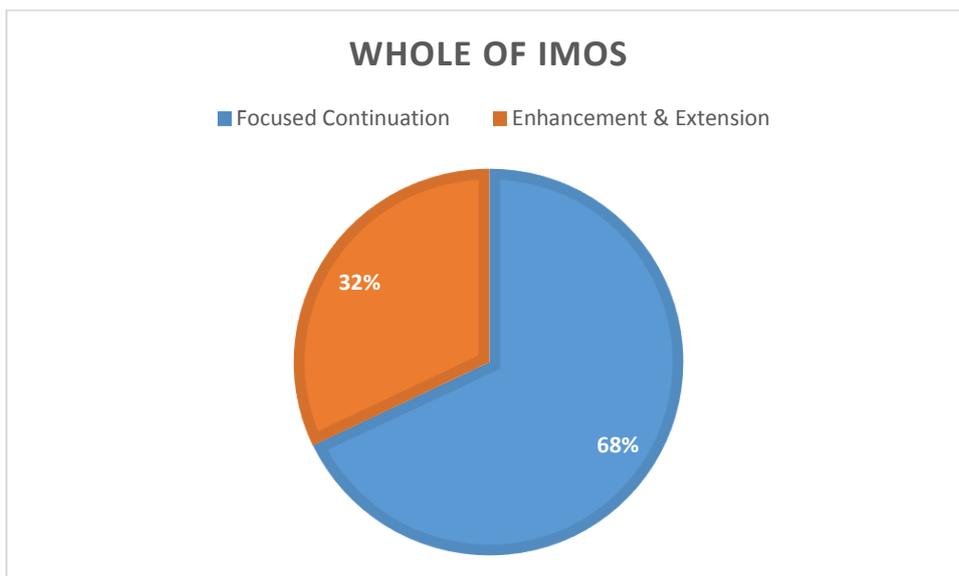
At the whole of IMOS level, this proposed portfolio would be distributed as follows:



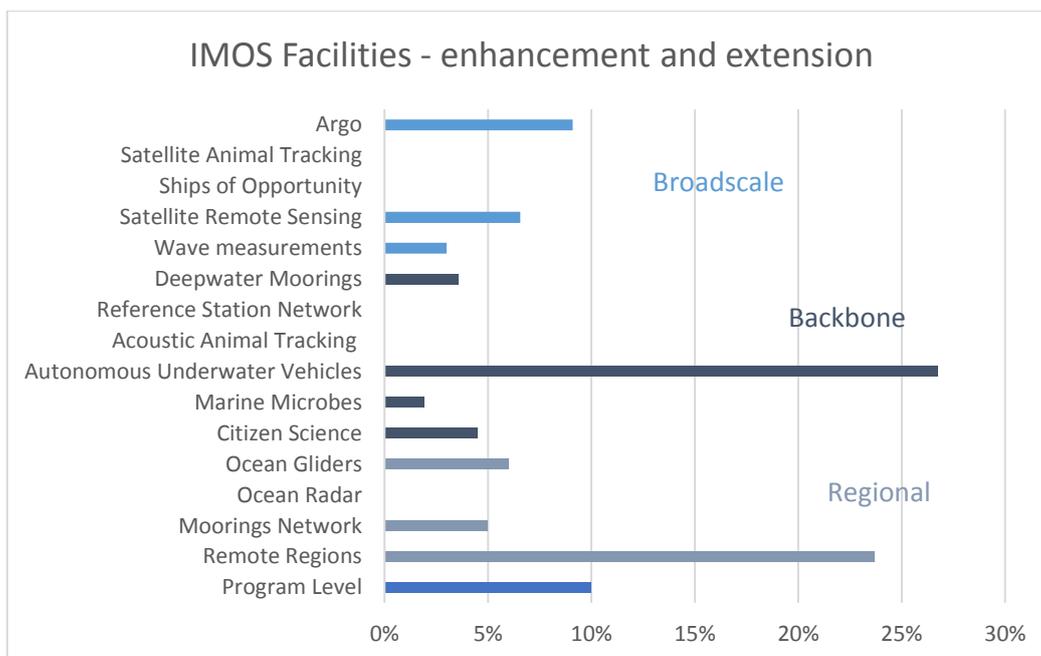
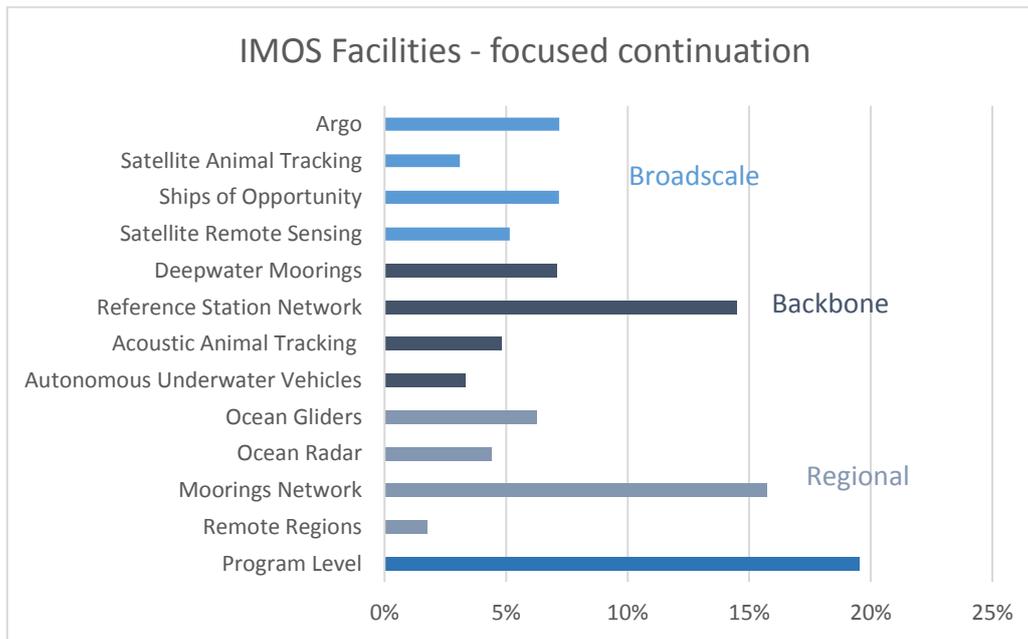
Key points to note:

- There is solid investment across all four dimensions, with none being sub-critical.
- There is a trend towards relatively increased investment in Backbone and Regional capabilities (62%, or 74% excluding Program Level), in response to demand from users and stakeholders.
- There is a strengthening at the Program Level around national marine data management, value added products, and proving new technologies.

The mix of focused continuation, and enhancement and extension, would be as follows:



This can be broken down to Facility level as follows:



Key points to note:

- The majority of investment (68%) is in focused continuation, to maintain IMOS as a world class research infrastructure in line with the Innovation Agenda and its commitment to NCRIS.
- N.B. Maintaining the IMOS research infrastructure does not mean *'status quo'* for the science and research output, and the impact it will have. In fact this will increase dramatically as the datasets and time series are used and reused, extended, and integrated. This has already been demonstrated through measurement of increased scientific output and impact over ten years to date.
- All of the IMOS Facilities warranting focused continuation are at critical mass. The smallest in relative terms is Remote Regions, representing available resources from wind back of current pilots to begin refocusing in response to user and stakeholder needs (see below).

- There is solid investment in enhancement and extension (32%).
- Particular emphasis is being placed on enhancement of IMOS to take on new science, new technologies and new variables in response to drivers and feedback. This will include a mix of maturing successful pilot activities, and piloting new activities where concepts have been proven. Less emphasis is being placed on extension of existing IMOS activities into new geographical regions.
- Proposed priority enhancements and extensions are as follows:
  1. Enhance Argo to include biogeochemical properties and deep ocean measurements.
  2. Extend Argo into the ice zone.
  3. Enhance remote sensing to exploit data from new international satellite missions coming on stream, and engage with the sea ice community.
  4. Enhance IMOS to begin investing directly in the measurement of waves.
  5. Extend Deepwater time series for improved seasonal climate prediction.
  6. Significantly enhance the AUV fleet with new vehicles and image handling capability, with a related enhancement of IMOS in citizen science.
  7. Enhance IMOS to invest in the measurement of marine microbes, subject to assessment of technical readiness.
  8. Extend Ocean Glider activity in the East Australian Current, and the continental shelves of NSW and WA (where use of gliders is most mature).
  9. Extend the Moorings Network in the northern GBR, and Bonney Upwelling/Bass Strait.
  10. Significantly enhance IMOS with additional capability to monitor in Remote Regions.

In summary, the proposed portfolio of Facilities appears well balanced in terms of major considerations for the IMOS Five Year Plan (2017-22).

## ATTACHMENT 1 – Drivers of the IMOS Five Year Plan (2017-22), from a stakeholder perspective

The key drivers for IMOS derive from the fact that it is a national research infrastructure; used by academics, researchers, and other users to deliver impact; funded by Australian Government; reliant on co-investment by partners; operating in a globally connected system; and making extensive use of technology (platforms, sensors, data and compute). Specific international, national, and regional initiatives that we need to consider in our forward planning include the following

	17-18	18-19	19-20	20-21	21-22
<b>International</b>					
GOOS Framework for Ocean Observing			OO'19		
GEO Blue Planet					
Open data access (ODIP, RDA etc)					
Southern Ocean Observing System (SOOS)					
Indian Ocean Observing System (IIOE-2)					
Tropical Pacific Observing System (TPOS 2020)					
<b>National</b>					
National Innovation and Science Agenda					
Industry Growth Centres					
National Science and Research Priorities					
National Marine Science Plan					
Marine National Facility ( <i>RV Investigator</i> )					
Forum for Operational Oceanography (FOO)					
Bureau of Meteorology (BOM) Marine Strategy					
Australian Antarctic Science Strategic Plan					
New, much more capable polar vessel					
Antarctic Climate & Ecosystems (ACE) CRC			?	?	?
Antarctic Gateway Partnership		?	?	?	?
Commonwealth Marine Reserve management					
National Environment Science Program (NESP)					
- Marine Biodiversity Hub					?
- Earth Systems & Climate Change Hub					?
- Tropical Water Quality Hub					?
Defence White Paper					
Bluelink					
Australian Research Council (ARC)					
Cooperative Research Centre (CRC) Program					
Fisheries Research & Development Corp. (FRDC)					
<b>Regional</b>					
Reef 2050 Long Term Sustainability Plan					
eReefs		?	?	?	?
Advance Queensland					
White Paper on Developing Northern Australia					
WA Marine Science Blueprint					
WA Marine Science Institution (WAMSI)		?	?	?	?
Marine Innovation Southern Australia (MISA)					
GAB Research Program		?	?	?	?
NSW Research Attraction & Acceleration Program					
Marine Estate Management Authority (MEMA)					
Victorian Marine Science Consortium					
Tasmania's Sector Growth Strategies					



University of Tasmania  
Private Bag 110  
Hobart Tasmania 7001  
<http://www.imos.org.au>