External Review of the Australian Ocean Data Network

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Report of
External Review of the Australian Ocean Data Network

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Executive Summary

The external review of the Australian Ocean Data Network (AODN; hereafter the Review) was charged with providing a forward-looking assessment and evaluation of the Integrated Marine Observing System (IMOS) AODN program and processes to ensure the AODN facilitates efficient and optimised data access and delivery of derived products to Australia's marine science community now and into the future. The Review was asked to consider the current and future capability (i.e., skills, infrastructure, partnerships) of the AODN program and to provide findings and recommendations to guide changes in the AODN.

The Review made 52 Findings and provided 13 Recommendations for the consideration of Review sponsors.

The Review conducted surveys and interviews of AODN stakeholders and peers and interviewed key personnel from the IMOS Office and the AODN. The AODN provided input against the terms of reference through a series of detailed presentations and meetings as well as self-assessment (benchmark rating) in selected areas of their activities. The Review found the input of AODN to be informative and constructive and wishes to acknowledge the significant contributions of the AODN Management Team and other AODN staff to the conduct of the Review.

The Review broke its charge into eight areas:

- (a)   Remit, scope and structure
- (b)   strategy and planning
- (c)   business processes
- (d)   human resources (capability, capacity)
- (e)   IT infrastructure, including architecture
- (f)   data ingestion
- (g)   data and product services
- (h)   benchmarking

The Report and synthesis and recommendations were organised accordingly (the findings in this Summary are hyperlinked to the main body of the Report).

Remit, scope and structure.   The Review concluded IMOS, and its national partners needed to clarify and distinguish between governance and activities of the national ocean data network and those of the IMOS group and program known as AODN (Finding 1). There should be a shared understanding of the organisational arrangements involving AODN, the IMOS Office, the AODN Technical Advisory Group (TAG), the National Marine Science Committee (NMSC) and the IMOS Science and Technology

Advisory Committee (STAC (Finding 2, Finding 6) and of the status of intergovernmental representation (Finding 3). The remit of the AODN should be adjusted accordingly (Finding 5). The organisational arrangements should clearly distinguish the roles of different IMOS entities (Finding 4, Finding 7).

> ***Recommendation 1***   *IMOS should provide added clarity around national provisions for ocean data management, in consultation with the NMSC, and adjust terms of reference, organisational arrangements and scope accordingly. A clear statement on the remit of AODN should be agreed.*

<u>Strategy and planning</u>. The Review found AODN had weak strategic planning and that this weakness impacted most areas of its work. The Review further found that the expected flow-down from national and IMOS planning, and upward influence from AODN was fractured and inconsistent (Finding 8). Stakeholders advised that IMOS and AODN needed to have a user-driven approach and that strategy and policy needed to be reset to reflect that (Finding 9). The planning cycle for AODN should be revised, with strategy guiding prioritisation, and with far greater transparency and engagement with stakeholders early in the planning cycle, prior to the annual planning meeting. Plans should include indicative schedules for the out-years (Finding 10).

> ***Recommendation 2***   *The AODN should develop a strategic plan, reflecting the high-level strategy of the IMOS Plan, but also identifying aims and priorities to guide AODN plans. Stakeholders should be engaged in this process. The Annual Business Planning cycle should be restructured to allow greater external engagement and increased transparency around priorities.*

<u>AODN business processes</u>. The Review found that the project management methodologies adopted by the AODN represent best practice and should be retained and strengthened (Finding 11, Finding 12). However, implementation of project planning in isolation has caused significant issues during roll out including (a) disconnect with Governing Board decisions, (b) poor recognition and buy-in from clients (mostly Facilities), (c) an over-crowded pipeline of work, and (d) excessive time and documentation devoted to the planning process. The AODN Project Management methodology (PRINCE2) was in wide use in Australia and IMOS should support IMOS-wide buy-in, but in a so-called Lite form that was more appropriate for small-to-medium projects (less than $1M; Finding 11).

An analysis of recent projects revealed multiple failings in the process; the coincident roll-out of Project Management was one contributing factor. The review concluded that IMOS should rethink its decision-making process for projects heavy in IT and involving AODN. The business case presented to the Governing Board should align with the expectations of Project Management, with clarity on the products/functionality required, and with a level of specificity that allows sound cost estimation (Finding 13). IMOS should also examine co-investment and costing arrangement for IT infrastructure projects (Finding 14).

> ***Recommendation 3***   *IMOS should adopt Project Management methodologies to support project planning and execution of IT projects, harmonised with governing body decision making processes as appropriate. Project Management implementation should be right-sized for the size and complexity of projects and AODN should reset its processes accordingly.*

Human resources (capability, capacity). The Review could not find any persuasive evidence that AODN was either over- or under-resourced relative to objectives of IMOS but does conclude it was under-resourced for the grander national objectives. AODN base funding included both core funding for operations and maintenance, and funding for project builds (refurbishment of assets and new builds). This was not unusual for organisations with significant assets and relatively short life cycles (5-10 years). Base funding was supplemented with finite term funding for specific projects. The base project funding was largely at the discretion of the AODN Director, while additional funding was determined by the Governing Board and the IMOS Office. Added clarity was needed to ensure IMOS and AODN had clear line of sight on investment returns (bang-for-buck; Finding 15, Finding 16). Weaknesses in planning and priority setting contributed to a perception in AODN and IMOS generally that AODN was under resource pressure. The expansion in IMOS facilities from 2018 undoubtedly added pressure and indirectly impacted core activities (delays, technical debt).

> **Recommendation 4** *The review does not provide any recommendation for a change in base funding but does recommend adjustments to process so there is a clear line of sight for (a) base funded operations and maintenance (core), (b) base project funding, and (c) fixed-term project funding.*

The Review found AODN staff enjoyed good levels of respect professionally and a rewarding work environment. Pressures from both the core and project pipelines manifested as increased stress on capability and capacity and a tendency for AODN to push back when faced with new demands (Finding 17). Several capability gaps were identified and AODN needs improved capability planning to better manage skill demands (Finding 18).

The Review also concluded that the short-term contracting arrangements for AODN staff contributed to high staff turn-over and disruption to both the core and project tasks. These arrangements were also a mis-match with the long-term strategy for IMOS and national data activities (Finding 19). Greater use of outsourcing could alleviate AODN specialist skill needs (Finding 20).

> **Recommendation 5** *AODN should put in place capability planning processes, including options for out-sourcing when special needs arise. IMOS should explore options for more secure staffing arrangements consistent with the IMOS long-term strategy for AODN, to improve position competitiveness and to mitigate high staff turn-over rates.*

Architecture. The Review recognized AODN successfully delivered a diversity of data in self-documenting architecture-independent open formats with widely used metadata standards and that this represented a significant achievement (Finding 21).

The Review clarified data flows into AODN (AODN data) and found several potential avenues to improve the architecture of the ingestion system, including consideration of recent changes in standards and the potential of systems available through the cloud. The Review also concluded IMOS, in consultation with IMOS partners, should improve guidance for data providers concerning (i) standards adopted for provider-AODN interface; (ii) general policy for quality control responsibilities which should reside with the data providers; (iii) conditions to be satisfied for data providers to be IMOS-approved and supported data flows; and (iv) the evolution toward a broader national data curation and publication role (Finding 22, Finding 23, Finding 24).

The Review concluded the pipeline architecture did promote scalability and efficiency but AODN identified several potential barriers, including the harvesting of data and metadata and technical debt (Finding 24). The Review found bespoke ingestion, processing, loading and publication/web services solutions proscribed against scalability, efficiency and agility in the architecture. If such solutions were deemed necessary by IMOS, cloud solutions should be preferred with sunset agreements to reduce legacy risks and costs (Finding 25).

> **Recommendation 6**   *IMOS and AODN should reset policy and guidance for existing and potential data providers so that (a) required data and metadata standards were clear, (b) differentiated responsibilities and accountabilities were clear, and (c) integration into the AODN architecture was strongly preferred.*

The Review found that the publishing and web services architecture was offering the user community diverse opportunities to discover, access and download data. The Reviewed noted greater exposure and understanding of the different AODN catalogues would enhance this impact (Finding 26). Some aspects of the web services architecture were dated and the Review encouraged AODN to evaluate options, including those offered by the cloud cf. AODN-built solutions (Finding 27, Finding 28) to better inform users of the breadth and depth of data accessible and downloadable (perhaps indirectly) from the main Portal.

The Review found there was an urgent need for review and resetting of AODN architecture, and that major infrastructure decisions and builds should be delayed until this was done (Finding 29).

> **Recommendation 7**   *AODN should undertake a review and reset of its architecture as a matter of urgency, with scalability and efficiency included in the criteria, and an overall aim of greater flexibility to introduce new technologies. The resetting should include greater consideration of cloud solutions where appropriate.*

IT infrastructure. The Review supported the AODN use of commercially provided web services and noted they provided important additional security and reliability for the AODN production systems. The Review noted several potential avenues for more effective exploitation of cloud offerings and greater use of proprietary systems (cf. self-builds) in the future (Finding 31). The Review noted an urgent need to improve handling of large (mostly gridded) NetCDF datasets and a need to find a more effective solution for querying and subsetting such datasets. The Review supported AODN plans to investigate cloud optimised gridded data services but also encouraged IMOS/AODN to seek improved forms to improve usability of data (analysis-ready), either through a tender or a partnership (e.g., under the NTP program) (Finding 31, Finding 32).

> **Recommendation 8**   *AODN should assign high-priority to the need to find efficient and effective IT solutions for handling large datasets including querying and subsetting capabilities.*

Data ingestion. The Review found that the ingestion and curation of IMOS observation facility data was generally effective and most stakeholders rated it as strong or better. The Review found AODN Workflows for data ingestion were well-documented and provided surety around responsibilities through the lifetime of data from instruments into the AODN. The attention to detail was

appropriate and admirable and should make the process stable and capable of managing disruptions such as changes in technology or personnel (Finding 34).

The Review identified an expectation of continuous incremental improvement and enhancement of the ingestion infrastructure (dataset-specific pipeline handlers, Toolbox, etc.). The Review found this to be unrealistic and likely a contributing factor to AODN over-commitment. AODN should reduce ad hoc incremental change and improvements in favour of a planned and orderly review and update cycle (Finding 35).

The success of AODN has led to demand to access its ingestion and curation system. IMOS has supported selected external data holdings to be managed as AODN data, but the Review found unmet demand, particularly around academic and other public data. Moreover, it appeared that some of the new facilities were unprepared for the rigours and demands of AODN data management. The Review found it would be helpful for AODN/IMOS to develop guidelines and policy for the IMOS data ingestion process (Finding 36). This guideline should also consider a position on legacy datasets, specifically observations related to Facilities but collected before IMOS came into existence. Users clearly expected such data to be presented in a unified way through the Portal, even if the form of the data proscribed against it being made discoverable, accessible and downloadable through AODN (Finding 37).

The Review found ambiguity in the accountability and responsibility for publication. For IMOS generated data the situation was clear, but for third party AODN data and republishing of national AODN partner data, the situation needed added clarity (Finding 38).

The Review found that the policy and practices around handling multiple versions of the same data stream and publication (including formal publication through the use of digital object identifiers) should be reviewed. This review should also consider scientific and technical guidance materials around the quality of the data and how to use available data (Finding 39).

> **Recommendation 9**   *Policy and guidance should be developed for the observation-AODN interface to make clear the differentiated responsibilities for quality assurance and quality control, the high standards on metadata and data, and the enduring responsibilities of data curation and publication that were borne by AODN.*

Data and product delivery services. The Review devoted considerable time to assessment of AODN data and product services, principally because of the extensive feedback received on the topic. There were differences of view, with some respondents focusing on the huge advances made by IMOS AODN, which the Review recognized, while others focused on what should or could be done to improve data services. Opinions on the impact of AODN data delivery services also varied; the Review considered them to be favourable (good, but not strong).

The Review found that despite recent attention being given to the demand for value added products, the present IMOS and AODN strategy was not sufficiently user-driven and user-focused and must be updated (Finding 40).

> **Recommendation 10** *IMOS, with input from AODN, should review and update strategy to ensure greater focus on users and usability with identified actions to achieve such change.*

The Review also considered the way AODN managed the relationship with users and identified a number of shortcomings, some of which derive from the lack of user registration, a process that might allow IMOS and AODN to gather intelligence on users and usage to inform future IMOS/AODN strategy. Such a process need not and should not hinder the commitment to open data (Finding 41). The Review found IMOS/AODN needed a dedicated channel (a User Desk) for soliciting user and client feedback and gathering intelligence on user demographics and IMOS data and product usage and future needs. It should be separate from AODN (Finding 42).

The Review found AODN needed to enhance its skills and competencies in user/client relationship management to ensure a culture that was user focused and that all elements of their work benefited from user feedback (Finding 43). As part of this process of change, AODN/IMOS should consider an annual or biennial user forum or similar mechanism to garner advice and input from Nodes, Facilities and other user groups. This should be convened mid-way through the planning cycle to properly inform planning and should be user-oriented (use cases, user needs, etc.), not a technical display (Finding 44).

The Review found that the lack of an active user uptake program meant that AODN and IMOS were being forced to push data and data products rather have having the pathway to impact facilitated by a community of value-adders. IMOS should consider creating a modest user uptake program to foster the development of innovation and user applications (Finding 45).

> **Recommendation 11** *AODN and IMOS should enhance capabilities and functionality for users including consideration of i) user registration, (ii) the creation of a User Desk, (iii) enhanced capability and capacity for user relationship management, (iv) a dedicated user forum, and (v) a system of user uptake grants.*

The Review found that a national strategy for agreeing standards for managing marine biological data, and for providing an effective (biological) data service was needed. The AODN/AODN TAG were well placed to lead such work from a technical perspective, but it was deemed essential to engage the marine biological community more broadly, including data providers and data users. The NMSC Monitoring and Baseline Working Group could facilitate such involvement (Finding 46).

The demand for changes and improvements in the AODN Portal was constant and enduring, and far outreached the ability of AODN to service those requirements. Changes to the Portal should be strategic and systematic; user community driven; feasible and viable within the limitations of architecture and IT infrastructure; and demonstrably impactful (Finding 47).

The present AODN Portal does not have the capability to manipulate or visualise data to meet a major demand from users for value-added products and visual/graphic material. IMOS needed to develop a specific strategy to meet this demand. AODN can contribute through co-design and co-development, as appropriate, but should make its focus the provision of effective data services to underpin this development. It was the opinion of this Review that the strategy should focus on facilitation rather than a new set of facilities within IMOS (Finding 50).

> **Recommendation 12** *IMOS and AODN, with its partners, should develop and agree a strategy specifically for (a) management and servicing of biological and ecosystem data, and (b) for developing value-added data and data products.*

The Review concluded the AODN Portal was at, or close to its end of life, with growing technical debt and a growing gap between where AODN should be and where it was now. Such a finding should not be a surprise in a world of rapidly changing standards and technology. A major refurbishment without substantial change in the architecture would likely not be cost effective or a viable longer-term solution (Finding 48). The current Portal should be frozen during the 2021-22 fiscal year and a plan for its replacement developed. The Review concluded there should be less self-build and more off-the-shelf/cloud services incorporated into its replacement. Its design should be user driven (Finding 49).

With respect to national AODN data services the Review concluded that AODN should continue to promote and contribute to a national interoperable network of marine and coastal data services with the AODN Portal providing a window to national data holdings. The AODN should also seek further opportunities to ingest, curate and publish national publicly funded ocean and coastal observations more generally (Finding 51).

> ***Recommendation 13*** *The AODN Portal, in both its national and IMOS manifestations should be replaced, to take advantage of new technology and to better position it to respond to future user needs.*

Benchmark advice was provided through surveys and interview and by AODN through self-assessment. AODN was rated favourable (but trending to strong) across its planning and business processes; as experience was gained and improvements were made with both strategic planning and Project Management it should move toward strong. The AODN Team was strong in some parts but had gaps and weaknesses in others, particularly when referenced against future AODN requirements. It was well-respected by its peers. Position security and staff turn-over weighed heavily on the assessment. AODN architecture was not well positioned and does require urgent technical review and resetting. IT infrastructure was generally well-positioned. Data ingestion processes were rated as strong, with several attracting benchmark rating from peers. Data services, however, were viewed less favourably, weighed down by expectation (perhaps unreasonably so) and limitations of the architecture. AODN leadership on national approaches to services was welcomed but many challenges remained (Finding 52).

External Review of the Australian Ocean Data Network

1. Background

1.1. Introduction to this Review

> **Purpose of Review**
>
> This is a forward-looking review examining the AODN program and processes to ensure the AODN facilitates efficient and optimised data access and delivery of derived products to Australia's marine science community now and into the future. The review needs to consider the current and future capability (i.e., skills, infrastructure, partnerships) of the AODN program.

This review was initiated by the Integrated Marine Observing System (IMOS) through its Governing Board. The Terms of Reference for the review were provided through a Statement of Work (Attachment A) and work started on 30 October 2020. The Terms of Reference cover the purpose of the Review (highlighted above), background and AODN remit, scope, principles, stakeholder consultation and some Review Report areas of specific interest.

The Reviewer was assisted by Mr Jeremy Tandy (The Met Office, UK) for some technical aspects, specifically around IT infrastructure and data system architecture. Brief biographies of the Reviewer and Mr Tandy are provided in Attachment B. While much of the Review focused on higher level aspects of the IMOS Australian Ocean Data Network (AODN) and was not overly technical, a Technical Glossary is provided at Attachment C to assist the reader, particularly with the discussion of IT Infrastructure. An acronym list is provided at Attachment D. Wherever possible, hyperlinks and footnotes are used to reference documentation and cite relevant material. Attachment E lists additional documentation provided to the Review, mostly from AODN and the IMOS Director.

1.2. Structure of the Report

The Terms of Reference were not itemized and tended to intersect the responsibilities and capabilities of AODN in different ways. To provide a workable approach for consultations and the Review Report, the Terms of Reference were broken down into tasks under the following headings:

(Section 2) Remit, scope and structure
(Section 3) Strategy, planning and process.
       a. Strategic planning
       b. Annual business planning
       c. Projects and Project Management
(Section 4) AODN Capability and capacity
       a. AODN Team
       b. AODN Infrastructure
(Section 5) Data Services
       a. Data Ingestion and Curation
       b. User Data Services - Impact and Responsiveness
           i. The AODN Portal
          ii. Data products and visualisation

              iii.   National AODN data services

(Section 6)   Benchmarking

Extracts from the Terms of Reference are included at the top of each major section to assist and orient the reader.

Findings of the Review are discussed and highlighted within individual sections and aggregated in Attachment J "Consolidated Findings" for convenience. Section 7 provides synthesis and a set of Recommendations.

1.3.   Stakeholder consultations

Interviews and surveys were used to inform the Review. Attachment F provides a list of the stakeholders who were contacted, largely following the guidance of the Statement of Work and advice from the IMOS Director and AODN Director. The response was good – 34 responses to the survey (also 4 emailed inputs; an initial target of 50), and 38 interviews (52 interviewees; initial target 20, many with an accompanying survey reply). The stakeholders were separated into seven categories:

- IMOS Facilities
- IMOS Nodes
- IMOS Partners
- Major stakeholders
- International peers
- AODN technical affiliates
- Users

All IMOS Facilities were represented and the majority of the IMOS Nodes provided input. The input from international peers was modest, most citing time pressures, lack of familiarity with AODN, and/or interference from COVID 19 as reasons to decline. This was partly compensated by the quality of some of the input that was received.

Survey forms were drafted for each category using a template that broadly followed the structure described above. Attachment G provides an example used for Facility leaders (note that in the survey, capability and capacity were addressed before looking at the effectiveness and impact of the input and output data services). Stakeholders were also provided a copy of the Statement of Work (Attachment A) and provided some additional guidance; they were advised to treat areas outside their knowledge as optional. All interview and survey materials were gathered on an in-confidence basis and, if quoted, were not attributed. Most survey respondents provided benchmark guidance, but it proved more difficult to get such advice in interviews. The feedback was of uneven quality, particularly from those stakeholders external to IMOS and thus unfamiliar with some of the areas of the Terms of Reference.

The interviews largely followed the same pattern as the surveys but were prone to diversions and undue concentration/time on areas of concern to the stakeholder. Most of the interviews were scheduled for 30-45 minutes during the three weeks leading up to the Xmas break. However around 20% were moved to the first half of January because of issues around availability. Many interviews

involved more than one person. Several stakeholders held multiple interests – for example, most Facility leaders were also concerned about data and product services for users.

Only a small subset of stakeholders expressed familiarity with the remit and internal processes of AODN or with the capability and capacity of AODN staff.

The IMOS Director and AODN Director were consulted multiple times. Six remote hook-ups were convened to discuss specific topics with the AODN Team:

Meeting 1) Interview AODN Director
Meeting 2) Overview and general discussion against the Terms of Reference
Meeting 3) Data ingestion
Meeting 4) Infrastructure and architecture (also attended by Jeremy Tandy)
Meeting 5) AODN Portal and data services
Meeting 6) Business practices and processes

PowerPoint presentations were provided for meetings 2 through 5 (the presentations are available at https://drive.google.com/drive/folders/18kMg3cR9eKZ-D7L3y2AS_2Kw6qtgQuVg?usp=sharing). After discussion it was decided that a separate written submission was not needed. Some self-assessment materials were provided separately. The inability to meet in person was disappointing but did not unduly hinder the Review. Email exchanges, mainly through the AODN Director, were used to clarify points and/or to address specific questions.

The input and engagement from AODN were of high quality, timely and a credit to the AODN Team.

1.4.   Other input

Attachment E provides a list of additional documentation provided to the Review. The IMOS Web pages also provided significant background material and technical details for the Review.

2. Remit, scope and structure

Aspects of the Terms of Reference to be addressed:

- Assess the AODN business model against the remit of the program to ensure the AODN can continue core business while also having the capability to support and deliver new/additional activities, priorities and data sets (i.e., ability to scale to future needs), derived data products and has the ability to maintain archived data for ceased activities. This review should consider the capability, effectiveness, efficiency and agility of the current program and operations.

  …

  d. Examination of the AODN remit.

2.1. Remit and scope

The Terms of Reference for the Review included a statement on the remit of the AODN. As far as this Review can determine, this remit was not stated or published prior to the commissioning of this Review and was not endorsed by IMOS other than through approval of the Terms of Reference for the Review. It appears to have originated from the AODN Team.

The remit appeared to be quite broad and suggested (point 1) "publicly funded data" should be ingested and published by AODN, not just IMOS-designated observations. This same point suggested the international community was a target user group. Point 3 suggested AODN "visualise and analyse data", but then referenced project management, a process that seemed out of place in a remit. Points 4 and 5 highlighted the importance of data sharing (access) and standards for AODN, but also implied an obligation to do this in response to all Australian marine needs. The last point referred to e-services and virtual research environments, initiatives that were highlighted in the 2015-2025 IMOS National Science Plan but may be misplaced in a statement of AODN objectives.

Stakeholders generally felt the remit was daunting, perhaps beyond the capabilities of AODN at this time, but none argued that the stated remit did not have relevance to national aspirations. The stretch in scope from IMOS observations and the research community to publicly funded data and the Australian community at large was consistent with the 2015-2025 IMOS National Science Plan which stated that IMOS added further value (to the previous IMOS eMarine Information Infrastructure - eMII) by "expanding the IMOS information infrastructure to create the Australian Ocean Data Network (AODN), through partnerships with the Australian Federal State and Territory Government agencies, Universities, and private sector companies". While all stakeholders concluded this leadership by IMOS was welcome and key from a national perspective, there was also substantial confusion, including within the AODN that was the subject of this review.

IMOS made the move toward a national role in 2010-11 when it made its infrastructure and support available as the basis for an Australian Ocean Data Network, a Network that was in principle supported by the leading marine Commonwealth agencies as well as IMOS. The AODN of 2010-11 was a loose federation, but with national objectives that were broader than those of IMOS and involved data service contributions from many sources, in principle at least. This 'national' AODN exists in concept now, as evidenced by references in the 2015-2025 National Marine Science Plan and in the terms of reference of the 'national' AODN Technical Advisory Group (TAG). However, this

Review understood that the national AODN was not the Australian Ocean Data Network that was the subject of this review, the program of work and capability funded directly by IMOS. The distinction between the IMOS program of work formerly known as eMII and 'national' AODN was made even fuzzier when the former was renamed the AODN in 2016. The IMOS (AODN) Portal and the national AODN Portal were merged in 2016.

Given almost all contributions to the AODN were led and resourced by IMOS, these changes were logical, but no steps were taken to communicate the significance of this change from a national and/or IMOS perspective nor to harmonize usage of the name AODN. The current AODN Team believed they inherited some or all of the aspirations and goals of the former national AODN as well as the obligations to IMOS, and this was reflected in the remit. Quoting from the AODN ABP 2020-21: "AODN now has a responsibility to report regularly to the NMSC on AODN activity. NMSC also has oversight of the AODN Implementation Plan". The 2015-2025 IMOS National Science and Implementation Plan talks of a "leading role" in developing the AODN, but this makes no sense if the AODN was an IMOS entity. We further noted that this Review was sponsored solely by IMOS, and not by the partners of the 'national' AODN[1].

> *Finding 1.*   *IMOS, in consultation with partners of the 'national' AODN, must clarify the distinction between the IMOS capability (and program) known as AODN (and the subject of this review), and the 'national' AODN for which IMOS was a leading contributor, but not the sole owner. This clarification should include consideration of objectives and governance.*

> *Finding 2.*   *The scope and remit of the IMOS AODN need to be defined and approved by the IMOS Governing Board so that the responsibilities and accountability of the IMOS AODN are clear and transparent to IMOS and external stakeholders.*

This Review concluded visualisation and analysis of data remained a tension point for IMOS and the AODN; Section 5.2.2 will provide a deeper analysis of the involvement of AODN in these activities but the Review was doubtful they should have appeared in the stated remit. Similarly, this Review found virtual research environments, while a legitimate interest of IMOS, do not at this time belong in the remit of AODN.

The word "International" appears in the remit, but not elsewhere in the Terms of Reference. Interoperability clearly depended on data managers around the world adopting similar standards and processes and, since many of the IMOS Facilities collaborate on international activities, it made sense that those standards have an international as well as a national basis. The (national) AODN Technical Advisory Group (which was also the Marine Data Sub-Committee of the National Marine Science Committee) provided a forum for developing data management and data publishing standards for the Australian marine community, but it also represented "the Australian marine community at national and international gatherings concerned with marine data" according to its terms of reference (see Attachment H).

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[1] Hereafter, and given the AODN of this Review is unambiguously the program of work and capability within IMOS, we will continue to use AODN for this purpose and refer to the broader collaboration among Australian marine agencies as 'national' AODN.

It was not clear to this Review whether this international responsibility formally passed to the IMOS AODN Director as part of the transformation from eMII to AODN (he believed it had). Feedback provided to the Review from the international community recognized that AODN made important contributions internationally, but the visibility of AODN within the Intergovernmental world (e.g., within the International Oceanographic Data and Information Exchange (IODE) programme of the Intergovernmental Oceanographic Commission of UNESCO) was low. This may simply reflect that AODN (like IMOS) was selective with international engagement and had not identified significant value from engaging in the work of IODE[2].

> *Finding 3.* *Additional clarification was needed concerning AODN's intergovernmental role and the extent to which AODN services should be driven by international requirements.*

The AODN engaged in relevant international communities, often with AODN taking the lead, but also sometimes shared (e.g., Gliders) or occasionally with the Facility taking the lead (e.g., SOOP). Such engagement needed to be purposeful and strategic and evidence provided by stakeholders suggested it was.

The Terms of Reference for this Review asked for an assessment of the extent to which the "AODN can continue core business while also having the capability to support and deliver new/additional activities, priorities and data sets (i.e., ability to scale to future needs), derived data products …". If this was an expectation (objective) of the current AODN, or an aspiration for a future AODN, then it was a challenging one, even before consideration of capacity, and it was an aspect not covered by the stated remit. For example, both the animal tracking and reef monitoring projects were creating capabilities that sit alongside, but not within the core AODN capabilities. They act against scalability. The choice appeared largely out of the hands of AODN. Novel data streams, for example data from the marine biome, involve pathfinder activities and developing the necessary capability and expertise; it could not possibly be scaled-up from current capability of the AODN.

Section 4 looks at capability and capacity issues in more detail and, in particular, attempts to identify policy, architectural and/or other infrastructure impediments to scalability and efficiency. It was reasonable, in fact probably essential, to identify scalability and efficiency as objectives, and within the remit of the AODN, but there should not be an expectation that the capability (and capacity) was indefinitely extendable and able to absorb new responsibilities without impact on core functions.

> *Finding 4.* *The AODN remit and objectives should identify scalability, efficiency and flexibility as important attributes of AODN functionality and capability in order for it to effectively support and deliver new data and products streams.*

2.2. Organisational structure

The direction and structure of international ocean data centres were often influenced by their hosts, in this case by IMOS and NCRIS. The Irish data service lies within an Institute specialising in

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[2] The lead figure for 'national' AODN prior to IMOS assuming the lead, Mr Greg Reed, was very active in IODE and held senior roles.

legislation and policy, not research or operations, and so its portfolio of activities was centred on public policy users with less emphasis on real-time data delivery or infrastructure suited to researchers. US IOOS data management systems were shaped by the regional implementation of IOOS and real-time (operational) data needs, and less by research. The current AODN was shaped by IMOS, but the future AODN may have deeper national responsibilities and a different "owner", e.g., for publicly funded data, and be driven by a much broader set of users, including industry, policy and environmental portfolios. IMOS needed to consider these long-term options when developing strategy.

IMOS adopted a policy of centralised data management, seeking efficiency and consistency in data ingestion and delivery services. Other international players, most notably the US Integrated Ocean Observing System (IOOS) have adopted a different strategy, with data management responsibilities devolved to the eleven regional nodes and policy around standards etc. used to ensure interoperability. None of the evidence provided to the Review argued for IMOS to change its approach, even if there were cases mounted for some of AODN's resources to be diverted to the Facilities; not surprisingly, many felt they could produce a solution for their own specific purpose more efficiently than a centralised facility.

The message from interviews with Organisations/Major Stakeholders (Attachment F) was unambiguously supportive of IMOS playing a leading role for national AODN. For example, "To me, there should be only one manager of observations, data, best practices, fully supported by the individual Facilities, and data providers, to avoid data fragmentation and scattering between multiple archives, to ensure homogeneous standards and practices, and acting as a consistent and sole reference point for the science community and the data users … a reference point for similar data centres overseas". Others cited the "independence" of AODN as a distinct advantage, moderating the competition between agencies undertaking ocean data management. While in part these views may be a simple reflection of the fact that IMOS has potentially more flexible resources (i.e., a cost-shifting exercise), when tested there appeared to be a genuine belief that IMOS was best positioned to lead and grow national capability.

Figure 1 shows one interpretation of the organisation of AODN within IMOS, relative to national organisational arrangements (grossly simplified). The other contributions to national AODN are not shown. It was not clear from published governance descriptions whether the AODN was a part of the IMOS Office or a distinct capability, like observation Facilities. It was also not clear whether the TAG had a formal role in advising AODN, paralleling the role played by STAC for scientific and technical (observational) advice. The STAC and Nodes assist/advise the IMOS Office. The NMSC was the "home" of national AODN. Some stakeholders interpreted the TAG as a steering committee (primary governing body) for national AODN, while others saw it as an advisory body only, as its name suggested. Many respondents, and AODN itself, highlighted the value of the TAG.

The term "Facility" was used variously as the name of observation capabilities and for any IMOS capability, including AODN. When IMOS was formed, the term was used solely for observational capabilities, much as it was used on the web page https://imos.org.au/facilities (New Technology Proving projects being an exception). The Review observed "facility" (or sub-facility) being used for New Technology Proving Projects, OceanCurrent, and for data contributions from outside IMOS. The Review concluded the terminology should be clarified, or the term qualified as in the diagram. At a

minimum, the primacy of observation Facilities within IMOS should be recognized as capability for undertaking systematic and sustained observing of Australia's marine environment, as stated on https://imos.org.au/facilities.

New Technology Proving (NTP) was beyond the scope of the Review, yet numerous references to NTP were made in the course of interviews and surveys, and in AODN presentations. AODN was involved in some projects, but also assumed because they were being referred to as facilities, that they should be included in their planning. Despite additional clarification provided by the IMOS Office, the Review was unable to determine how NTP should be treated in AODN strategic and annual business planning.

> *Finding 5.*   *The Review concludes that added clarity was need around the organisational and strategic links between AODN, facilities, Nodes and the NTP projects.*
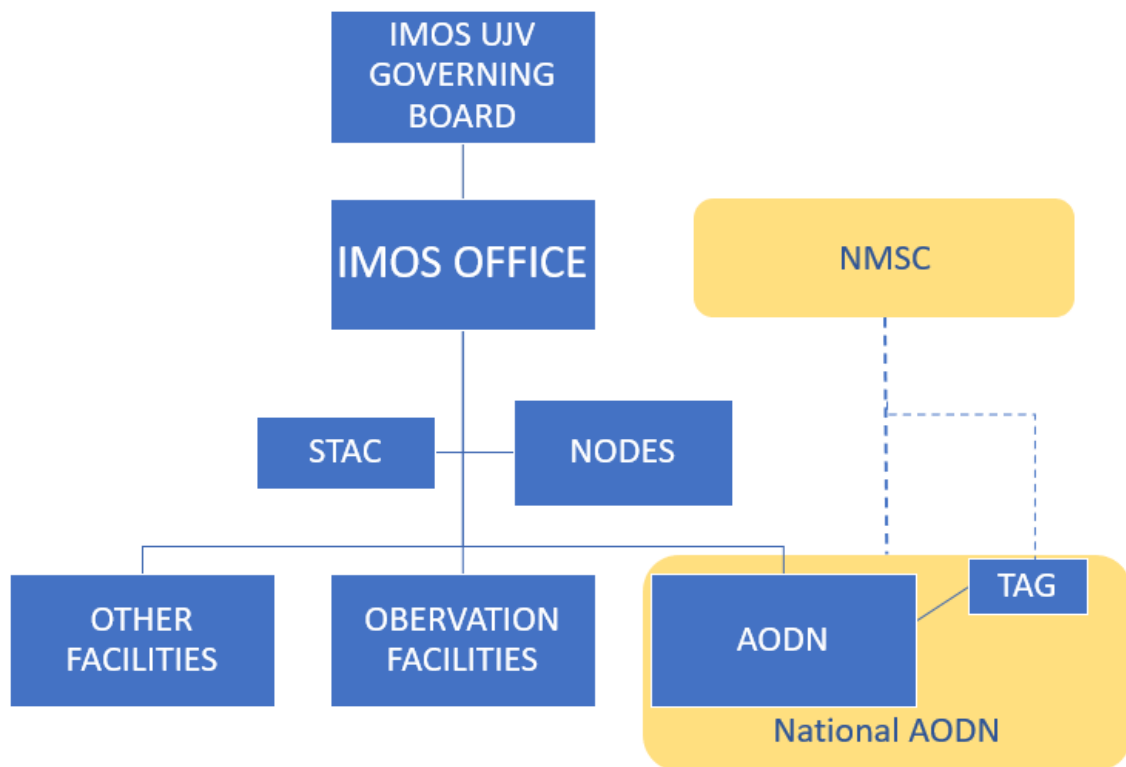

Figure 1 The organisation of AODN within IMOS, and the relationship to national entities.

As discussed in section 2.1 above, the relationship between national and IMOS AODN responsibilities should be clarified, either through the IMOS Governing Board (preferable; the principal partners sit on the Board) or through the NMSC (see Finding 1).

The TAG Terms of Reference (Attachment H) were recently revised. Finding 1 noted issues around IMOS AODN and the national AODN. The terms of reference refer to both – the name in the title refers to the national entity, not the programme of IMOS. The Review found:

(i)   The name should be the National AODN Technical Advisory Group.

(ii)   The dual listing as the Marine Data Sub-Committee of the NMSC contributed to confusion. The sponsors of the national AODN need to clarify the governance arrangements.

(iii)   The Review was unable to find any formal definition of Australian Marine Data Landscape, though we were advised the terminology was in wide use in IMOS and the NMSC; its meaning should be clarified.

(iv)   The second point under Purpose can be simplified for clarity: "Provide technical advice to the Australian marine community regarding publication of marine data and on data enabled platforms".

(v)   IMOS must consider whether there should be a specific line of advice to IMOS under Purpose; the Review concluded there should be.

(vi)   The fourth point under Functions needs to clarify whether one of the Co-Chairs should be designated as the focal point for IODE.

(vii)   The last three points under Functions all relate to AODN of IMOS and implied a formal advisory role to IMOS/AODN; such an arrangement needs to be confirmed by IMOS and, if agreeable, be recognized in its governance structure and formally reflected in sponsorship of the Group. If not agreeable, these terms should be removed.

Finding 6.   *The Terms of Reference of the Technical Advisory Group need to be reconsidered by IMOS in the light of other Findings of this Report. The references to AODN in the Terms of Reference need added clarity as does any formal relationship with IMOS.*

The IMOS Science and Technology Advisory Committee (STAC), a recent innovation, was an advisory body reporting to the IMOS Director. The AODN Director was a member. From the published terms of reference, it was unclear whether the STAC scope extended to data management and Information Technology; given AODN was not referenced directly, and the AODN Director was the single IT expert on STAC, it would appear not. The implication then was that review/assessment and opinions of STAC were confined to scientific and observational technology. The Review assumed that the AODN would be used by the IMOS Director to garner advice/opinions on information technology proposals, though the Review could not find a reference for that arrangement. The purpose of the presence of the AODN Director as a member of STAC was not clarified in the terms of reference; assuming the STAC has a policy for conflicts of interest, the AODN Director would recuse himself from any discussion of proposals that included AODN as a participant.

The Review formed the view that the AODN Director should not be a member of STAC but should be present as an observer or ex-officio, representing AODN, to avoid any perception that the STAC has the expertise to assess/provide opinion on data management and associated information technology. If, on the other hand, IMOS believes STAC should be constituted to provide advice and opinion across all activities, then additional expertise should be included.

Finding 7. *The organisational arrangements for AODN within IMOS and nationally need to be clarified, including a definition of facilities and added clarity regarding the role of the STAC with respect to data management technology.*

Finally, a small point around the use of "Director". Both IMOS and AODN were led by Directors, with one reporting to the other. This was an odd situation and explains in part why several correspondents thought IMOS was a part of AODN and/or in equivalent organisational positions. IMOS might wish to consider alternative titles.

3. Strategy, planning and process.

Relevant aspects of the Terms of Reference:
I. Assess the AODN business model against the remit of the program …
II. Provide recommendations on improvements to current practices …

The review scope should include:

        …
    d Examination of current processes for business case development and project planning to determine: 1) if there are ways to streamline while maintaining the capacity to manage internal and external expectations, and 2) whether current planning processes accurately predict project development timelines.
        …

3.1. Strategic planning

3.1.1. Context provided by IMOS Strategic Plan

The nine priorities of the "IMOS Strategy 2015-2025" supply strategic direction for AODN. Three of those priorities bear directly on AODN strategy (emphasis added by the Review):

2. <u>Continue to focus on turning observations and data into time series of essential marine and coastal variables</u>, providing timely support to a wide range of science and research, meeting current and future needs.

4. Sustain established IMOS capability so as to realise full value from investments to date, and avoid loss of value through discontinuity. <u>Evolve established capability in response to scientific and technological developments, and performance and delivery.</u>

5. Position IMOS capability so as to <u>maximise benefits from related investments in</u> remote sensing, vessel operation, <u>marine data management</u>, and ocean and coastal modelling.

Priority 2 aligns with the central role of AODN, to make observations discoverable, accessible and downloadable. The reference to "time series of essential … variables" was interesting, revealing IMOS intent to prioritise this type of data product. The 4th priority placed emphasis on "performance and delivery" for established capability such as AODN; there was an expectation of efficiency and effectiveness, and "delivery" could be taken to mean a more active role in ensuring data does reach the targeted users. Priority 5 implied a positioning of IMOS to exploit and benefit from other data managers, akin to the expectation for a national AODN. It also encouraged AODN to position itself so that IMOS could benefit from non-IMOS observational capabilities, e.g., ingesting, managing and publishing strategically relevant data.

Priority 3 related to positioning within the International community: "Embedding all IMOS Facilities in relevant international programs". It was not clear whether that was intended to apply to AODN as

well; as seen above, AODN was well connected at a technical level with international groups but has not established a profile in IODE.

The broad strategic direction for AODN was on page 10 of the IMOS Strategy:

> *Open access to all IMOS data and ongoing development of a broader Australian Ocean Data Network (AODN) in partnership with other data custodians, with a particular emphasis on marine industries and State Governments.*

This vision did recognize the dual roles – for IMOS and for the "broader" national AODN – and good progress was made in some areas with industry (e.g., wave data) and State data (e.g., IMOS partner facilities).

3.1.2. Context provided by the National Marine Science Plan 2015-2025

This Plan provided a "vision of an interoperable, online network of marine and coastal data resources supporting science, education and management needs", fully embracing a federated, standards-based approach to give Australian marine science a competitive edge. This was fully consistent with IMOS strategy and the approach to building a national AODN drawing on IMOS AODN infrastructure.

However, the Plan provided little insight on the actions and commitments required of marine agencies to deliver against this aim. IMOS was not the only entity with skills and capability in data management and the objectives of the National Marine Science Plan 2015-2025 could only be achieved if all entities agreed on a joint strategy (as was envisaged with the Australian Oceanographic Data Centre Joint Venture) and jointly committed to actions within that strategy. This appeared to have been the IMOS intent, but the current federated model fell short of that vision. The work program of the (national) AODN TAG was a contribution to the objectives, particularly with respect to technical standards, and a federated approach seemed sensible, but both must be backed by committed action.

3.1.3. Elements of an AODN Strategic Plan

AODN has not translated the overarching IMOS strategy into a strategy for its program. Annual business planning and engagement in the IMOS annual planning cycle demonstrated awareness of the context within which AODN was working, but the lack of a documented and published strategy inhibited planning within AODN and reduced transparency surrounding priority setting and decision making for IMOS, particularly in relation to observation Facilities. Paradoxically, it seemed that through the (national) AODN TAG, the national marine community had more insight, at least from a technical perspective.

Some respondents questioned the effectiveness of AODN communications, specifically around plans and commitments. The lack of a published strategy obviously contributed, but there were also questions around communication of decisions and priorities.

Finding 8.   *AODN should develop a strategic plan, probably with a 3-5 year horizon,*
consistent with and following IMOS Strategy and developed alongside the IMOS 5-year plans.
AODN clients should be engaged in the development of this Plan.

There were at least six areas that should be addressed in AODN strategic planning: a) ingestion of Facility data, (b) publication of and access to IMOS AODN data holdings, (c) people: expertise, skills, capacity, (d) infrastructure: architecture, capability and capacity, (e) impact/benefits, and (f) the national AODN. The following goals are proposed (cf. the remit discussed in section 2.1).

Goal 1. To ingest, curate and preserve all data and relevant metadata collected by IMOS and other non-IMOS facilities, as deemed appropriate by IMOS.

Goal 2. To make all AODN data (as indicated by Goal 1) discoverable and accessible and provide a user-focused data service/portal that is efficient and effective using content and delivery-based standards.

Goal 3. To manage AODN human resources so that the right capability (skills, expertise) is available and to provide a working environment that values productivity, innovation and performance.

Goal 4. To provide IT architecture and infrastructure that is scalable, efficient, flexible and effective and has the right levels of capability and capacity.

Goal 5. To contribute as appropriate to IMOS plans for value-added data aggregations and products and for visualisation of data and products.

Goal 6. To provide advice and leadership on the adoption and implementation of data and metadata standards across the marine science community.

Goal 7. To promote and contribute to a national interoperable network of marine and coastal data services.

The IMOS/AODN Policy settings and/or strategy need to be adjusted to ensure all AODN-held data have the best opportunity for impact. Data aggregations and value-added datasets were often preferred by researchers, including the modelling community. They were generally not willing to stitch together deployment organised files, or separate passes/profiles. In some instances, e.g., deep water moorings there were Facility-AODN joint projects to achieve this. Section 5.2.2 discusses this topic in more detail.

The management of biological data was a fast-moving area, characterised by rapidly evolving standards, methods and best practice. AODN (and national AODN) have a significant role, first to catalyse joined up actions (e.g., agreeing requirements), and then to facilitate nationally agreed systems, not necessarily all focused in AODN. The Review recognized potential value in a coordinated approach to management of biological data, starting with agreement on strategy and priorities, under the NMSC umbrella, and with AODN involvement (see section 5.2.1.2 for further discussion).

The Review was unable to find explicit IMOS strategy and/or policy covering value-added data products (e.g., aggregations of EOV data across platforms; gridded representations of spatial data; derived fields such as mixed-layer depth). eMII/IMOS started with an aim to make all observation Facility data discoverable and available to the research community, and not just to the researchers involved with the Facility. This was largely achieved for the first Facilities. Having achieved that, the

Review expected IMOS Policy to shift to prioritise actions to make the data easy to find and use, with minimal knowledge of the Facilities or the form used to store the data. That is, a user-driven policy setting rather than a Facility driven policy. Such a strategy may have been communicated verbally to IMOS facilities, but it needed far greater prominence and support. The strategy for added-value data products and synthesis should be led by IMOS but with tangible buy-in and contributions from others (section 5.2.1.1).

New Technology Proving Projects. Several projects were approved that have a direct bearing on the future strategy of AODN, including mooring data aggregation and visualisation of data. Correspondents were unsure of the overarching strategy – were they supported because they were interesting and potentially impactful instances of new technology, or were they supported because they align with long-term strategy and needs of IMOS? AODN engaged in several of these projects but the strategy behind this engagement was not clear to the Review.

> *Finding 9.* *The IMOS/AODN Policy settings and/or strategy need to be adjusted to ensure all AODN-held data have the best opportunity for impact, including through value-added products. Added clarity was needed around the strategic alignment of New Technology Proving projects and AODN, to guide planning for engagement.*

3.2. Annual business planning

AODN annual business planning worked on fiscal years and was in synch with IMOS Annual Planning, though AODN input to IMOS planning appeared to be managed differently (reactive cf. proactive). Annual Planning meetings (around February) provided an avenue for exchange of information and feedback. When respondents were queried on the effectiveness of this approach, many noted that this was the only opportunity to engage with AODN and that it always appeared that their plans were firm/final with little to no room for adjustment or negotiation. AODN fended off suggestions and inquiries rather than engaging in a dialogue.

AODN regarded the Annual Planning meeting as the sole opportunity to expose their priorities and detailed task list, and to provide context for the demand-pressure they were under. The intent was not to garner sympathy, but to expose the reality of a unit with demand outstripping their ability to service them. Historically, they were not encouraged to engage directly with Facilities or Nodes; the IMOS Office facilitated the coordination process, and some Nodes had zero visibility of the AODN planning process. This ultimately resulted in lack of transparency and AODN plans which seemingly could not be moved or respond to needs. To their clients, AODN plans always appeared to be in an advanced and firm state at the time they were shared.

Many respondents acknowledged the difficulty of planning in an environment where demand was almost always out-stripping AODN's ability to serve it. To quote one "All researchers clamour for better data access all the time, so it was a noisy environment to try and plan in … it was again a difficult line to walk between supporting and fostering a user community, versus building tools for them." There was a triple challenge (combining thoughts of several respondents):

- Keeping up to date and exploiting fast moving technology
- Being steady, reliable, secure … dependable and long-term

- Responding to an ever more demanding and critical user community, who arguably may never be fully satisfied.

Strategy should have provided the starting point for annual plans and an overlay for the prioritisation process. In their absence (see section 3.1), annual plans tended toward detailed lists of tasks, some pulled from the shelf of pending/unfinished tasks, some core maintenance requirements, and other projects/tasks from IMOS (projects agreed by the Board; priorities identified by the IMOS Director, etc.). Prioritisation of the tasks was performed by AODN, but informed/adjusted by any directions from the IMOS Director. AODN planning was also advised by the TAG (see section 2.2) but this appeared not to be a strong influence and often occurred late in the cycle. AODN plans were also presented to the NMSC but more for information than with an expectation of receiving useful feedback.

The Review concluded such a planning process was a recipe for stress and strain within AODN; for dissatisfied clients within IMOS; for unfulfilled expectations; and for an ever-growing list of tasks that could not be completed. Planning was technical rather than user/client focused.

Annual plans should not be task driven but strategy and client/user driven, with sufficient engagement and transparency to ensure all of IMOS was informed and respectful of the prioritisation process. Change to the current Fiscal Year plans should be the exception, and only accepted when IMOS production and/or reputation was at risk; if accepted, there should be full transparency and communication around consequent reprioritisation and scheduling. Incremental improvements should not be a core funded line.

The Annual Planning meeting appeared to be too late in the cycle to begin the process. Engagement with the Facilities and Nodes should begin in November/December, mainly in listening mode – no mention of technical deficit or stressed capability or capacity but briefing on strategic goals and direction and on commitments. Plans should have at least a two- to three-year horizons so that the end of the FY was not seen as a hard border for plans – more focus on specifics for the coming FY, broader for the out years. The current AODN Annual Business Plans may still be relevant for internal scheduling.

> *Finding 10.* *The planning cycle for AODN should be revised, with strategy guiding prioritisation, and far greater transparency, and engagement earlier in the cycle, prior to the annual planning meeting. Plans should include indicative schedules for the out-years. The Annual Planning meeting should be used for finalisation and buy-in.*

The plan should include allowance for urgent tasks (see above and section 4.1.1) and allowance for important unexpected tasks and scheduled maintenance. There should be strong and persuasive justification for any new task outside those agreed through the annual planning process; sign-off will usually be at the discretion of the AODN Director, but for changes that have a material effect on the primary AODN deliverables, the IMOS Director should be the approver.

3.3. Projects and Project Management

3.3.1. Implementation of PM by AODN

AODN adopted standard project management (PM) methodologies in 2019, in recognition of the fact that four or more major IT projects were scheduled by IMOS and that AODN needed to improve project delivery. PM has been mainstreamed in Australian Government agencies and certain PM competencies were mandated for major IT builds after the 2008 Gershon Report on ICT[3]. AODN acknowledged that prior to 2019 AODN often "missed the mark regarding timelines, task orientation, meeting expectations" and that there was unclear tasking of AODN staff[4]. Several respondents aligned with AODN's self-assessment, though the majority did not have any firsthand knowledge of AODN business practices or the move to formal PM.

On a day-to-day basis the AODN teams adopted an agile project management methodology known as Scrum[5]; this Review found Scrum was widely adopted among AODN peers and several commented that the AODN implementation was consistent with best practice. A full assessment of its implementation within AODN was beyond the scope of this Review but from the input provided by AODN we find no reason to raise any issues in this area.

For larger project builds AODN adopted the PRINCE2 methodology, a methodology that was in wide use in industry and government within Australia (but not always for ICT), including within agencies who were partners in IMOS and the national AODN. AODN noted that there was one important variation in their implementation of PRINCE2 with respect to the Project Board because the customer, user and supplier were usually all from IMOS. While the Reviewer does not claim any deep expertise in PM or PRINCE2 (though this was the methodology employed by the Bureau of Meteorology), the situation of AODN does not seem particularly different or exceptional; there was no reason why stakeholders from the benefit area could not be drawn from the Nodes or other IMOS users.

PM was adopted by AODN alone and not by IMOS, meaning key stakeholders like the Facilities and the IMOS Office were not trained or familiar with the methods. The Facilities in the main recognized the reasons for AODN adopting more rigorous PM but did not recognize any changed requirements in their role. The documentation was regarded as a burden and a drag on implementation, not as an aid to successful execution. The IMOS Office was identified as the Sponsor of projects, but without any agreement of what that role entailed. Perhaps most critically, the decision making of IMOS in the form of the Governing Board was not integrated into the PM process, which meant business cases[6] were developed and signed off outside the PM framework. The ramifications of that failure

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[3] https://www.governmentnews.com.au/gershon-ict-review-to-be-implemented-in-full/

[4] Australian Ocean Data Network Project Management, 2019, provided by AODN.

[5] Scrum is an agile project management methodology or framework used primarily for software development projects with the goal of delivering new software capability every 2-4 weeks.

[6] The business case is the document that is the basis for approval of the project, confirming the project outcomes are desirable, viable and achievable for the specified resources.

have been exposed with both the National Reef Monitoring Network implementation and the Animal Tracking web project, both of which are discussed in more detail in Attachment I.

The examples provided by AODN of the use of PM were different in several aspects. First they were "initiated" by a business case document that really was not a business case; The AODN logic was that in the absence of appropriate PM documentation in the form of a Project Initiation Document or Business Case being the basis of the Governing Board decision, they needed to create a look-alike document. The documents were similar to a PM Project Plan, but mostly with excessive detail under Scope – a list of technical function descriptions cf. a product description. AODN also broke out some projects (e.g., LTSP) into multiple "business cases" for reasons the Review did not understand. The distinct products should have been the basis for separate work packages within a single project structure. The Project plans also tended to be too technical and task oriented, but perhaps that was to be expected for IT builds.

> **Finding 11.**   *The Review found that adoption of PRINCE2 by AODN alone led to several unintended consequences. PM should be endorsed by IMOS for use by AODN and ensure Facilities and the IMOS Office are fully briefed and familiar with the method. While it would be preferable for the PM methodology to be adopted throughout IMOS, including for decisions of the Governing Board, the fallback is to introduce processes that ensure decisions and resource allocation are consistent with the requirements of PM planning and implementation.*

> **Finding 12.**   *The Review found that project management methodologies adopted by the AODN (Scrum and PRINCE2) represent best practice and should be retained and strengthened for the future. However, variations to normal PM practice inevitably led to some frustration for both the sponsors and the clients.*

The principles behind good governance of projects were not complicated and mostly follow common sense. There should be a project manager responsible for the execution of the project; this was usually someone different from the individual(s) who line manage/control the resources. The latter role(s) was to ensure resources were made available to the project in a timely manner, and according to the plan. Oversight of the project (referred to in PRINCE2 as the Project Board) was provided through representatives of the major stakeholders – those resourcing the project, those supplying capability, and those who were the primary beneficiaries. For AODN, the first would usually come from the IMOS Office; the second from AODN management (but perhaps also from relevant Facilities); however, the third was a little harder. Often projects were pitched by Facilities, nominally for the benefit of the user community, but the Review often found the Facilities acting as (or for) the user community as well. This was not ideal. It was important that the individual sitting on the Project Board was able to confirm that the intended benefits of the project were being realised. In principle, Node members could perform such roles for IMOS.

If the Project Plan was professionally written (and based on a sound business case/project initiation documentation), and the project was managed and executed well, the Board may only be required for initiation and for completion/closure. If, however, the project needs resetting, realigning or any other adjustment that materially affects the project resource requirements, outcomes or benefits, it was the project Board that was the decision-making entity. Most other issues and risks can usually be managed within the project.

When implemented poorly, PM can manifest as unhelpful bureaucracy and paperwork. It was important to match the level of complexity of the PM to the level of complexity and risk posed by the project. So-called "lite" PM[7] was appropriate for most AODN projects – less than $1M of resources, a small number of sub-project elements/work packages (less than ten), and known and manageable risks. Reporting should also be "lite". Note that adopting "lite" PM does not downplay the difficulties of implementing IT solutions where rapidly changing technology and difficult technical interfaces often pose considerable challenge. The level of documentation should be the right size for the task. There was no formula that this Reviewer was aware of (though there were many texts such as the one cited in footnote 7); success usually came from on-the-job learning and mentoring from those experienced in PM. The IMOS partners collectively have that experience. Technical and scientific people often do not make good Project Managers, though there were exceptions. PM was a specialist skill and AODN should be developing such skills (several of the AODN staff have been trained in PRINCE2).

The decision-making processes of IMOS were out of scope for this Review. However, the Review concluded it was relevant to comment on what was required in order for AODN to be responsive to those decisions and be successful at project execution.

The Business Case[8]. For the purposes of this Review, this was the documentation upon which decisions of the Governing Board or IMOS Office to proceed with a project were made (see footnote 6 above). There were two elements of the business case that were crucial for IT Projects. The first was adequate product documentation (the functional requirements), with sufficient specificity to determine the feasibility, viability and effort required. For project initiation this would typically be a single page. If it was an IT build, the document may include technical specifications, and one would expect the decision maker to seek advice on the product and the viability of the project goals. The second was the costing which described the resources needed by the project. In large organisations it was common to have both the CFO and CIO sign off on these details. For IMOS, these roles fall to the IMOS office and the AODN Director. The decision will set expectations in terms of delivery – when and how long.

Steps for Approval. The technical complexity of data management projects represented a challenge for decision makers. Governing bodies will usually not have the expertise within to evaluate the appropriateness or feasibility of a proposal in detail. A widespread practice was to introduce steps (gateways) and to base the initial decision on a high-level business case which focused on the products, benefits and outcomes, accompanied by initial best estimates of the functionality and required effort and resourcing. In some cases, there may be sufficient detail and confidence to make a final decision; in other cases, a provisional decision can be made subject to a more detailed plan being developed within the parameters of the original business case. Sign off on the project may be delegated to the IMOS Director if, in the Governing Board's view, there was confidence a Project Plan can be delivered within the scope and resourcing outlined by the proposal. In other cases, the

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[7] Lite PM is a practical, yet minimalist, approach to project management that is sufficient for successful execution but without excessive process and documentation. See for example "Project Management Lite: Just Enough to Get the Job Done...Nothing More", by Juana Clark Craig.

[8] In PM this is often embedded in the Project initiation document.

Governing Board may wish to reserve its final decision until such time as the Project Plan was complete.

Managing the work pipeline. AODN was a medium-sized unit with an annual budget in excess of $2M. The significant commitment to maintenance (business as usual) limits the ability of AODN to manage and implement multiple projects and to bring the right skills to the project at the right time. PM has helped AODN cope, but the rapid increase in sub-facilities from 2018 (many heavy in the data management area), new investments in New Technology Proving projects, and approval of a range of other projects, severely tested AODN capacity and planning/scheduling in the view of this Review. AODN was aware of the pending crush but the Review found they were unable to plan and schedule on a time frame that kept all stakeholders content. Both the AODN and IMOS Office needed better preparation and planning.

Good processes. The Review was satisfied the AODN made the right decisions with PM. However, to roll it out in isolation and in parallel with the rapid expansion of IMOS capability was extremely risky. It takes time to bed down good process and good practices, and this was made harder by the increased demand coinciding with PM implementation. The fact that Facility leaders and the IMOS Office were not brought along on the PM journey exacerbated the level of difficulty.

> *Finding 13.* *The IMOS Office should consider a two-step decision making process for proposals that were heavy in IT and involve AODN, with the first step seeking approval for the high-level plan and intended outcomes, and the second for endorsement at a detailed level. The business case should be informed by adequate product description/ functional specification and rigorous costing. The pipeline of work for AODN should be tracked and managed with the IMOS Office to avoid overload and ensure essential core activities were sustained at the same time resources were brought to individual projects.*

3.3.2. Analysis of key projects

The Review was initiated in part because of questions around project implementation and the effectiveness and efficiency of AODN processes. Much of the concern was focused on projects that had undergone, or were undergoing planning and implementation during 2019-2021. While a full end-to-end examination of these projects was beyond the scope of the Review, there were clear lessons to be learned , many of which have been incorporated into the findings above. An analysis of some projects is provided at Attachment I "Analysis of Selected Projects".

3.3.3. Cost, Price and Co-investment

The Review found AODN was in a rather unique position with the vast majority of its activities funded by its parent, and this despite the fact it was playing a leading role in national AODN, for which IMOS was just one partner. IMOS was the sole investor in AODN, cf. other IMOS capabilities/facilities where there were multiple partners and generally matching co-investment. This raised the question of whether IMOS/AODN was leveraging its investment sufficiently, and whether AODN was partnering effectively to broaden its resource base and/or recover part or all of the costs of its work. In other words, was the return on investment in AODN adequate?

The Review was advised that AODN was not expected to generate income for IMOS/AODN and no respondent raised issues with this policy. The flip side of the question was whether IMOS and AODN were used as a potential target for alleviating and/or addressing resource shortfalls of partners. The NRMN community was attracted to IMOS because it offered new and stable investment at a time when other avenues had disappeared. The ATF community leveraged IMOS to enhance their penetration and impact, aspiring for a world-leading web service capability. Has the IMOS/AODN paid too great a price for this aspiration, and should the costs have been shared more widely? [We note this comment is not intended as a criticism of either ATF or NRMN who engaged professionally and effectively with AODN.]

A more dynamic resource base for AODN would have several advantages (generating additional income for IMOS was probably the least important). First, increased co-investment in AODN projects enhanced participation and contributed to both IMOS and national AODN goals. Several projects have in-kind investments, but these were not a replacement for real co-investment – having skin in the game, investment at risk. Second, AODN capability and capacity can be managed more easily if it was not solely dependent on IMOS funding: flattening the demand curve and reducing the peaks and troughs. Finally, such an approach encouraged a more rewarding and business-like approach to costing and pricing. For example, the Marine National Facility has identified five streams of activity, ranging from fully funded granted access (the main use) to commercial use (rarely exercised), with the price for use of the Facility adjusted accordingly.

AODN does have a diverse portfolio of work, with some funded externally (e.g., ARDC backed wave projects; Biodiversity Platform backing for the marine biome), and for the most part the net benefit for IMOS was clear, including diversification of the support for AODN capability. Improved strategic planning and clearer pricing/cost recovery guidelines would enhance the effectiveness and impact for IMOS.

> *Finding 14.*   *The AODN should be encouraged to broaden the base of investment in its activities, seeking co-investment and external contributions as appropriate. Pricing and cost recovery guidance should be developed to ensure projects deliver benefit to IMOS/AODN that was commensurate with investment by AODN.*

4. AODN Capability and capacity

Relevant aspects of the Terms of Reference:

…

    b   Examination of current IT systems and processes for maintenance and expansion of the existing AODN data infrastructure. Including consideration of fitness of purpose of existing systems and determining if there are alternative systems/processes that could increase efficiency and reduce the amount of effort directed to maintenance.

    c   Comparison of infrastructure and performance to programs with similar remit, including data delivery, infrastructure development and maintenance, project delivery (e.g., software or system development projects) and derived data product delivery.

…

    e   Assess if the AODN capability is adequate and appropriate to fulfil and deliver the remit, strategy and overall AODN program as well as IMOS strategic directions.

…

4.1. AODN Team

4.1.1. Staffing levels

The published Annual Business Plans (ABPs) of AODN (eMII) and IMOS provided staffing levels and budget information for the last decade and longer. IMOS underwent many changes during this period, all with flow-on implications for AODN. The IMOS Office and AODN were partly shielded from the budget pressures immediately prior to the current funding agreement.

Table 1 provides information for the current financial year and for two other FYs (totals only). The average budgets of IMOS and eMII over the first five years 2006-2011 were $7.2M and $973K, respectively, with eMII consuming 9.1% of the budget on average (capital expenses of IMOS in the early years were relatively higher). The initial guidance in the planning for IMOS was 10%[9]. This percentage has increased in the decade since, reaching 11.7% in 2014-15, but decreasing to 11.0% in 2020-21.

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[9] Personal recollection!

Table 1. Staff level and total budget for select years*. Note that the leaders of the two technical teams were considered members of the management team.

	Skills	People	EFT	2019-20	2014-15
AODN Management, support	Plan, execute, support, PM	3	2.8		
Information Infrastructure team	Software Engineer, DevOps	11	10.1		
Data services team	Data scientists, metadata	9	8.0	EFT	EFT
	TOTALS	23	20.9	18.2	17.6
	BUDGET			$2.37M	$2.22M

According to the 2020-2021 AODN ABP, "operational activities to ensure the infrastructure was reliable and all available data was discoverable, accessible and downloadable were the largest element in the team activities" (referred to as core), consuming around 70% of the budget, with the remainder invested in projects and change. Maintenance and day-to-day operations represented a substantial and growing commitment (in terms of EFT) as new data streams were brought on board, even more so when the ingestion systems were bespoke and requiring specialist attention (e.g., the Animal Tracking and National Reef Monitoring Network; see section 3.3 for further comment). The Review also found that it was common practice to include a level of incremental change within the core component. For example, "Implementing new features in response to user feedback" for the Portal and incorporating "new features" into the Matlab Toolbox used for ingesting mooring data (ABP, 2020-21). Systems/tools seemed to be "frozen" only when a major build was underway.

There were around 5 EFT positions devoted to non-core activities, split between software engineers and data scientists. These resources were largely devoted to projects (infrastructure builds) and the number varied depending upon the intensity of new work.

The Review could not find any persuasive evidence that AODN was either over- or under-resourced in terms of core funding, though there were arguments given for both. For example, "AODN was thinly staffed for what it was trying to achieve, and this reduces its ability to effect change. Uncertainty in funding on the longer-term also places risk around persistency of the data sets AODN curates". The Review interpreted this comment as saying IMOS AODN was under-resourced for the national AODN objectives it was trying to achieve.

AODN presented itself to IMOS stakeholders as an over-stretched, forever busy unit, with next to zero flexibility; this encouraged sympathy for the 'under-resourced' argument, but also created perceptions that AODN were not well organized and were unwilling to engage in a discussion around priority settings. This Review concluded weaknesses in planning (see sections 3.1 and 3.2) were likely to be a contributing factor. The AODN first reaction has to change from 'we are fully committed and cannot possibly do what you ask' to 'thanks for the input and we will take this into account as we formulate our plans, consulting as needed'. The Review did find that the pipeline of new work into AODN from 2018 to 2020 presented severe challenges, exacerbated by too little forward planning (by both IMOS and AODN), immature PM practices, and poor project initiation (AODN, clients and sponsors).

Finding 15.   *The Review could not find any persuasive evidence that AODN was either over- or under-resourced with respect to the objectives of IMOS but does conclude it was under-resourced for the grander national objectives. The IMOS investment in data management is comparable to or less than international counterparts. Weaknesses in planning and priority setting have likely contributed to a perception in AODN and IMOS generally that AODN was under resource pressure.*

The Review formed the impression that AODN had been block funded in the past; that is, a level of funding was decided (appropriated) and a set of services to be provided by AODN set down. These services ranged from routine data ingestion and data publication and delivery to new pipelines/capability for data ingestion and delivery. The AODN adjusted resources for activities internally. Though the Review was unable to confirm this impression, the AODN of today shared some of this character (Figure 2). Base funding covered both business-as-usual tasks (maintenance, etc.) and regular project work; in the growth phase of IMOS, and perhaps for the most recent growth phase, such an arrangement allowed many IT builds to be run in parallel. This base funding was supplemented by specific project funding and, on occasions, external support. Under pressure, AODN "borrowed" core resources to support projects, with consequent delays in business-as-usual work (a type of technical deficit). High staff turnover also contributed to delays.

The appropriation of resources to AODN (base funding) needs better definition and increased clarity. Core functions should be defined and agreed by IMOS and restricted to just those functions that were essential for keeping established systems operating; incremental improvement and/or discretionary tasks should not be part of the core functionality. Plans for core activities should reach out for 2 or 3 years so that there was transparency and confidence in the maintenance schedule. Non-core activity, principally for project builds and improvements, should have a plan-build-execute-release structure, consistent with the AODN PM framework, and be funded and scheduled in agreement with the IMOS Office, and published so that there is complete transparency. As discussed in section 3.2, maintenance issues should be classified as a) urgent, b) important but not urgent, or c) discretionary. Only urgent tasks should be absorbed into core activities for the current FY work program.

Finding 16.   *The appropriation of resources to AODN needs better definition and increased clarity and should be broken down into i) core, ii) internal project, iii) external project, and, if appropriate, iv) external contributions to core activities. Contingency should be built in for urgent maintenance issues.*
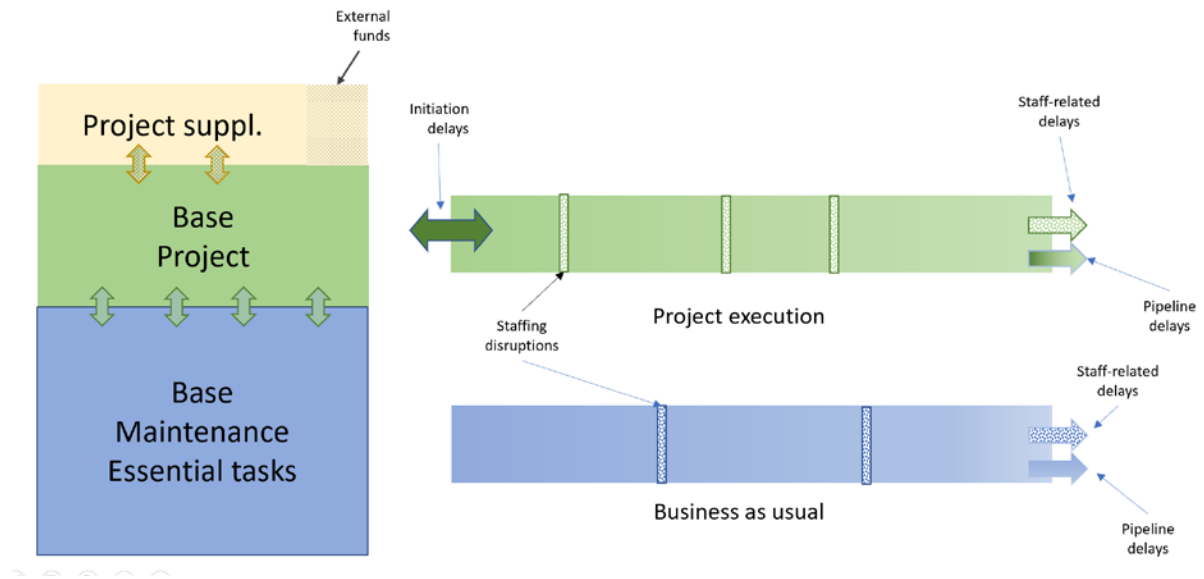
Figure 2. Schematic of base and project funding arrangements. Work pipeline pressures resulted in borrowing from core to feed projects (left panel). Staffing disruptions pipeline/core shifts led to delays in initiation and project execution.

4.1.2. Assessment of capability.

AODN indicated that in its view it had a highly collaborative work environment with emphasis on collaboration and communication: "we were all in this together" was their motto. The experience from various meetings and interviews with AODN staff generally supported this view.

Feedback from respondents was limited. One argued that the current AODN team is "… too technically-focused (weighted towards programmers/developers), with not enough focus on catering to end-users and data contributors". The Review did find evidence to support the first gap (lack of skills in client relation management and in working with users) but concluded the latter (data contributor focus) likely resulted from rapid expansion into new areas and a tendency for contributors to seek individualised attention. Another respondent wondered "whether they were able to attract the best people".

The Review conclusions mostly aligned with the AODN self-assessment (Table 2). The current Team collaborated extensively, even in projects that have otherwise been contentious (e.g., the Animal Tracking web upgrade). The lack of good strategic direction meant collaboration may not always have been in the right areas at the right time.

Table 2. AODN self-assessment of the Team organisational/people capabilities.

Capability	Assessment
Collaboration	Well placed
Talent	Development area
Learning	Development area
Accountability	Well Placed
Productivity Improvement / Efficiency	Development area

Finding 17. *The surveys and interviews revealed significant good will and respect for AODN, generally with the caveat that they have a very difficult task in front of them. Some were glowing in their praise for what AODN does, particularly around the ability to manage IMOS data. On the output side, issues with capacity and expertise (not enough science expertise in certain areas) were highlighted.*

The Review was not able to commit to a full capability analysis and thus our remarks about staff capability, learning and progression, and performance were limited. The skills mix in the AODN Team (see Table 1) was similar to that of equivalent teams elsewhere (e.g., the BODC), noting that in AODN as elsewhere there was considerable multi-skilling. Several areas emerged as potential areas for future strengthening:

- Business analytics, and associated costing
- Database administration
- AODN architect
- Client relationship management/user interface
- Data scientists for merging areas like reef monitoring
- Dedicated project manager
- More skills for the user interface (might not be in AODN)

These skills were partly covered by the present staff who multi-skill. AODN should avoid organic growth in favour of a strategic and planned approach to recruitment.

Respondents highlighted the need to strengthen access to business analysis skills to bridge the gap between IT and the IMOS business. The skills needed included using data analytics to assess processes (e.g., managing requests), determining requirements (e.g., user requirements from the biological community) and delivering data-driven recommendations and reports to the IMOS Executive and Board (e.g., Portal usage; efficiency of the AWS).

Finding 18. *AODN should undertake a capability assessment with the assistance of a facilitator experienced in capability planning in IT technical organisations with a view to developing a capability plan. This assessment should consider staff development activities and career opportunities for AODN staff, irrespective of contracting arrangements.*

The management approaches used by AODN seemed sound and consistent with modern practice but could benefit from deeper skills analysis and a documented capability/people plan. AODN skills/talent appeared to be well placed (favourable to strong from the survey; see section 6) but with risks around single points-of-failure and long-term security of positions (see below). For example, during the period of this Review 4 technical staff resigned, and there was an intense round of recruitment to fill the gaps and respond to project needs.

Staff development activities were limited and mostly restricted to technical training. There may be opportunities within the University of Tasmania and/or partner organisations for mentoring and fostering career development. Staff performance appeared to be managed professionally but the Review was not able to review this area in detail. Performance assessment and career development were difficult to implement in an environment of short-term contracts where the terms of the contracts were in effect the performance criteria, with little or no incentive to exceed the target. The Review was unaware of any routine individual performance feedback gathering process, e.g., from the Facilities.

4.1.3. Contracting arrangements.

All AODN staff were on short-term contracts (typically 12 months). IMOS was hosted by the University of Tasmania as the Lead Agent and drew its funding from NCRIS, with the IMOS funding terms varying historically from one to three years until the current agreement which runs for five years. The funding was not permanent or guaranteed (that is, there was no Australian Government Budget line devoted to IMOS with a rolling 4-year forward cycle), but history suggested there was secure and firm commitment. The stability of IMOS investment was in part due to its determination and commitment to the long-term strategic view rather than focusing on potential short-term disruption, and to management of the risks and changes as part of business as usual. This strategy was not replicated in AODN staffing arrangements.

While all observation Facilities were funded on finite-term contracts and short-term contracts for staff were the norm, the situation for AODN seems at odds with IMOS Strategy and national plans which were positioning AODN as a core national long-term repository and provider of ocean data. Short-term contracts, while appropriate in many circumstances, are notorious in terms of staff turnover and recruitment, on-boarding and training overheads. The Review was informed of incidences where key personnel were lost (sometimes recruited by IMOS partners into more secure positions) and significant delays were incurred as a result. AODN has mitigated some of the risk by reducing the number of single points of failure through multi-skilling, but job insecurity remained a factor and posed a high risk for continuity and consistency within the organisation.

Around 10 staff have been with IMOS for 10 years or longer which AODN management took as an indicator of the attractiveness of its work. However, as this Reviewer knows first-hand from his earlier roles, long-stay employees can also be a sign that staff were unable to compete for positions elsewhere and/or were not motivated to take on new challenges. The evidence provided to the Review generally supported the notion that AODN staff enjoyed the working environment and collectively possessed the right skills and competencies, but few correspondents were willing to argue AODN capability was outstanding or exceptional.

Advice available to the Review suggested an employee employed for four or more years on successive fixed-term contracts may be viewed as a permanent employee under some circumstances. For example, Russell Kennedy Lawyers advise "an employee engaged over a number of years under a series of fixed-term contracts may be able to argue that they have a continuing expectation of employment and were actually employed on an ongoing basis"[10]. The Fair Work Commission has noted (in relation to dismissal/failure to renew a contract) that where there has been a series of fixed-term contracts and renewal was a mere formality the Fair Work Commission may look beyond the terms of the contract to the reality of the employment relationship. All AODN staff employed on base funding would seem to fall within these considerations.

These issues were of course a matter for the University of Tasmania to consider as the Lead Agent and employer of AODN staff and there may be impediments to changing the employment arrangements. However, this may also be a matter for the IMOS Board to contemplate (if it has not already done so). The risk and reality are that IMOS partners, many of whom were also in the business of data management, and others, have a distinct advantage when competing for skills given the better opportunities for security and advancement that they can offer.

> *Finding 19.* *The short-term contracting arrangements for AODN personnel was at odds with AODN's long-term mission to provide reliable curation and archiving of IMOS and other data, and inevitably leads to higher turnover of staff and higher recruitment costs than would otherwise be the case. The Review was informed of several instances where loss of staff had a material effect on efficiency and effectiveness. IMOS should investigate more suitable arrangements.*

4.1.4. Outsourcing

The Review was not aware of any attempt to outsource skill or short-term capacity requirements; it appeared that all shortfalls were met through a recruitment process. In general, both international and national peers tended to make much greater use of outsourcing to supplement their capability/capacity, particularly where specialist skills were required for a finite period. Out-sourcing does require skills in tendering and contracting, but the current staff have sufficient experience to learn these skills, particularly if IMOS partners were able to provide mentoring around process.

This Reviewer was not sufficiently across the market for such skills to know whether there were likely to be savings and/or gains in efficiency, but it seemed highly likely that AODN and IMOS would benefit. The recent projects for Animal Tracking and Reef Monitoring were two examples where such arrangements might have been more effective than new recruitments. The University of Tasmania does use such arrangements in areas similar to AODN and their experience could be drawn upon.

> *Finding 20.* *IMOS and AODN should test the pros and cons of out-sourcing in place of recruitment for future project builds.*

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[10] https://www.russellkennedy.com.au/insights-events/insights/risks-associated-with-fixed-term-employment-contracts

4.2. AODN Infrastructure

4.2.1. Background

Unlike other sections of this Report, this section draws very heavily on the input of the AODN Team (Meeting 4 and email exchanges), and advice from an external expert. Few of the stakeholders consulted as part of this Review had expertise in IT infrastructure or architecture, and even fewer had knowledge of AODN internal technical operations. On the advice of the Review sponsors, the Review devoted specific attention to AODN infrastructure architecture (section 4.2.2 below); 4.2.3 covers other aspects of IT infrastructure, but in less detail, with the agreement of the Review sponsors.

Section 3.1.3 outlined the views of the Review in terms of important strategic thrusts for AODN. Goal 4 was "To provide IT architecture and infrastructure that is scalable, efficient, flexible and effective and has the right levels of capability and capacity." This provides the context for the discussion below.

The AODN was conceived as being a service sitting in between the data providers and the users to aggregate a wide range of data (and metadata) in one place – to streamline the process of searching for and gathering data for users. Data providers contributed to a rich set of complementary data. In the words of one respondent "The fact that users can now freely go to AODN as a one-stop central source for almost all marine data … is something of immeasurable benefit". The current AODN capability was an enormous advance on where the community was even ten years ago, and the advances included sound architecture and powerful IT infrastructure. In the following section we examine the strengths and weaknesses of this architecture and provide guidance for the future.

4.2.2. Architecture

4.2.2.1.   General description

AODN architecture accommodated the following data flows:

1. Data flowing from IMOS (and agreed partner) facilities[11] with agreed arrangements and/or workflows and data and metadata managed and published by the AODN team.
2. IMOS data that were curated elsewhere and harvested and published by AODN.
3. Other national data that were managed and curated by IMOS partners in accordance with AODN Portal requirements and that can be accessed through the Portal via harvested metadata.
4. Other national data holdings for which AODN provides a metadata catalogue but no data access or download services.

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[11] These included observation facilities, data management facilities (the observation activities are not within IMOS), and higher-level product facilities such as OceanCurrent.

A little over 50% of the datasets derived from data flows 1 and 2; Data flow 3 was the other dominant pathway, mainly for agencies who have adopted the AODN stack (IMAS, NIWA).

Four principles were used by AODN to guide the architecture:

1. Standards-based to support interoperability (formats, web services, metadata, legal)
2. Open data
3. The FAIR principles (Findable, Accessible, Interoperable and Reusable)
4. Open-source software

The approach enjoyed wide support among respondents, particularly achievements aligned with the first principle, e.g., "Delivering such a diversity of data in self-documenting architecture-independent open formats and with widely used metadata standards was a momentous achievement in its own right – one I don't believe the AODN ever gets enough credit for". The Review supported this view.

> *Finding 21.*   *The AODN has delivered a diversity of data in self-documenting architecture-independent open formats with widely used metadata standards and this was a momentous achievement in terms of architecture and infrastructure.*

AODN data was in principle open but some exceptions have been agreed (e.g., acoustic tracking data; embargos on annotated imagery). These were policy decisions of IMOS not AODN. These exceptions had direct implications for the architecture. The "Open data" principle was also interpreted to mean users of the data should not have to register in order to use IMOS data; this will be discussed in section 5.2 (the Review has formed a view that registration should be encouraged and eventually made mandatory).

The FAIR Principles have been widely adopted for the ocean data management[12] and the Review found most stakeholders appreciated and supported this as a principle. Some commented that findable/discoverable can be achieved in degrees – easy, hard, extremely difficult – and for the AODN Portal discovery was not always easy. The architecture has strict metadata requirements for Portal data to enable faceted search capabilities but even this did not ease the degree of difficulty for many users. For example, one respondent noted "AODN has been widely recognised as the primary provider and aggregator for much of the physical ocean data; however, it was not always seen as a preferred source of marine biological data. Much of the issue here relates to the organised aggregation of many data sources".

The open-source approach was generally welcomed; it was not implemented as a hard constraint, particularly since the switch to Amazon Web Services (see further comments below).

Figure 3 shows the architecture of the AODN system as interpreted by the Review, drawing on AODN's description. The middle and lower part of the Figure corresponded to data flows 1 and 2, while the upper part represented data flows 3 and 4. Observations were ingested through a

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[12] https://www.frontiersin.org/articles/10.3389/fmars.2019.00471/full

standardized pipeline process and stored in the AWS S3[13] file system (as NetCDF files). A subset of the data were indexed and stored in a geospatial Postgres database, for use by Geoserver. Several services sit on top of the stored data and offer end users a variety of ways to access the data. Geoserver was used for serving non-gridded data while AWS-WPS was used for gridded data.
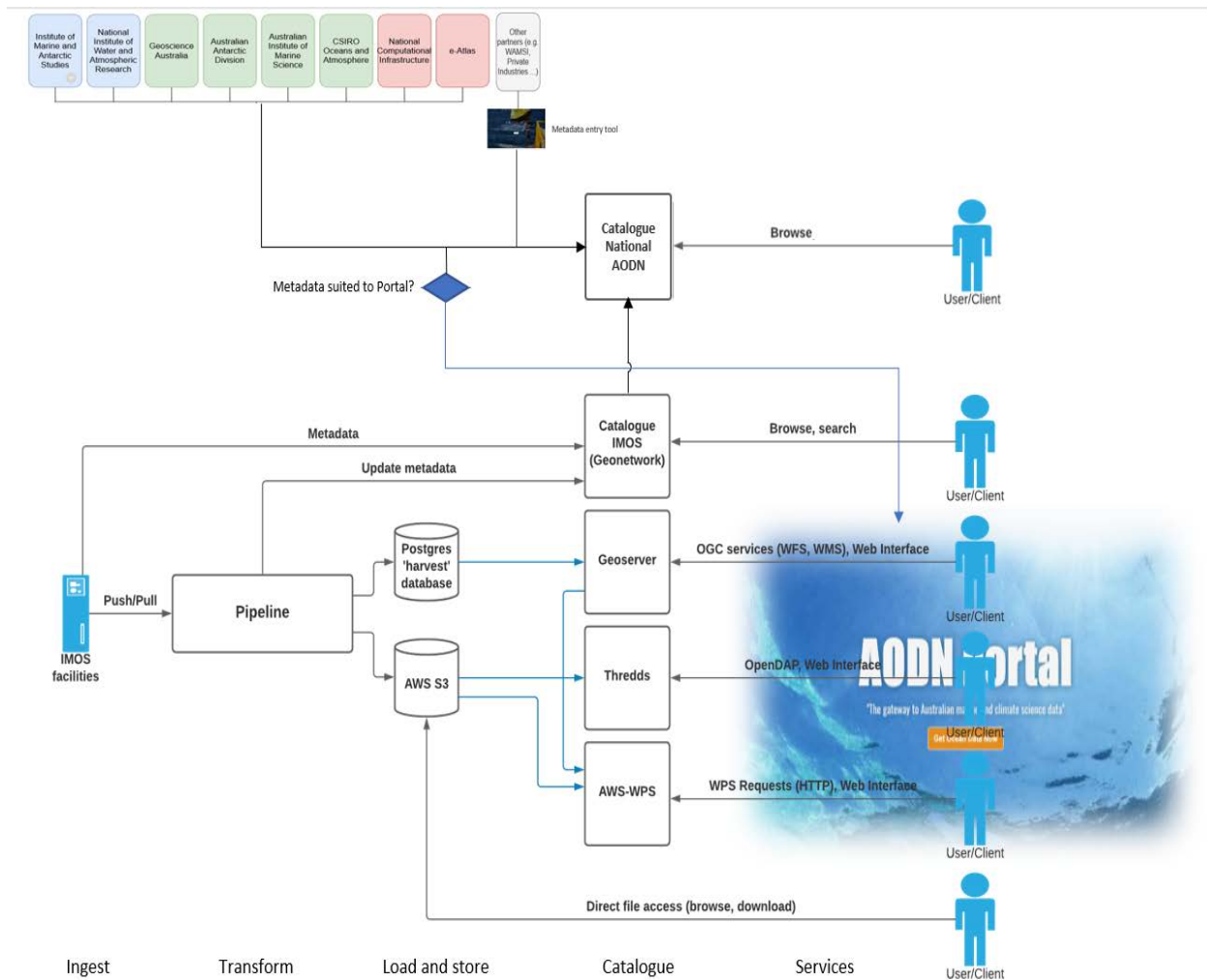
Figure 3. Schematic of the AODN architecture (adapted from AODN). Data flows 1 and 2 move data from facilities through to storage and then are published in the AODN Portal. Data flows 3 and 4 at the top source metadata from national AODN contributors and combined with IMOS metadata into the National AODN Catalogue. A subset of the metadata that satisfies AODN Portal requirements are provided to the AODN Portal (Catalogue).

4.2.2.2.   Ingestion and the importance of standards

The standard-based approach was widely supported in the community, aided by the work of the TAG. The Review concluded AODN had supplied significant leadership and resources to encourage convergence around national standards. By enforcing standards on the data ingested and providing standard output formats to users, the data resources of IMOS and its partners have achieved more

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[13] Technical terminology is explained in the Glossary at Attachment C.

impact. AODN set a high bar for contributors but provided assistance and tools to encourage uptake (mandatory for facilities). The Review concluded this decision enabled scalability and efficiency. One respondent made a salient point about the trend toward more formal adoption of standards: "If there's an evolving [trend], it's end users starting to dictate standards based needs, mostly through decision support requirements. … The latest work in Ocean Accounting by DAWE identifies standards based data collection and integration as critical for success. NESP2 has raised the bar considerably for decision support and data management …. we ignore these indicators at our own peril". The Review supported this view.

The Review found some unawareness around the policies behind the architecture of the ingest process and concluded IMOS (and IMOS partners) should provide explicit guidance and policy for data ingestion, including the standards adopted for the interface; the preference for QC to reside with the provider; conditions to be satisfied for data sources to become IMOS-approved and supported data flows; the evolution toward a national role (the alternative pathways 3 and 4).

> *Finding 22.*   *IMOS (and IMOS partners) should provide policy for data ingestion, including (i) the standards adopted for interface; (ii) the preference for QC to reside with the provider; (iii) conditions to be satisfied for data sources to become IMOS-approved and supported data flows; and (iv) the evolution toward a national role (the alternative pathways 3 and 4).*

Several other aspects were highlighted by the Review:

- Several respondents asked for better tools to check/confirm the readiness of datasets for ingest.
- Recent changes to OGC standards may provide opportunities for AODN, specifically around reducing the barriers for data flow into AODN.
- There were questions around the efficiency/reliability of the upload process, with implications for scalability. AWS Batch appears critical for scalability.
- In the light of conclusions from section 2 and the potential expansion of responsibilities for ingesting data beyond IMOS and its partners, the Review concluded:
  - A national AODN role will demand lowering of the data flow barriers, including consideration of the capability and capacity of potential providers.
  - Several of AODN's international peers make extensive use of ERDDAP, including for inward data flow. This may have a bigger role in the future. The JCOMM OpenGTS project might provide pointers.
  - Opportunities should be explored for promoting and, perhaps partially supporting, external parties to develop data ingestion Apps.
  - The WMO Information System provides an example of a broadly adopted set of standards for submission and exchange of data and potentially was a rich source for metadata/data relevant to the IMOS community. IMOS/AODN should explore this opportunity with the assistance of the Bureau of Meteorology.
  - AODN should consider emerging standards like W3C DCAT2 [Data Catalog Vocabulary (DCAT) - Version 2 (w3.org)] to lower the barrier of entry. It was noted that there was a trend away from complex ontologies toward simpler topologies.

Finding 23. *The Review identified several potential avenues to improve the architecture of the ingestion system, including consideration of recent changes to the OGC standards and the potential of systems available through the cloud (AWS).*

The Review discussed potential barriers and degrees of difficulty for external players using data flow types 3 and 4:

- Must provide a Web Map Service (Easy)
- Must supply metadata using controlled vocabularies (Medium)
- Provision of download services (Hard)

AODN was often required to provide coordination/assistance. While the Review respected the IMOS strategy to facilitate engagement in the national AODN (section 2; Finding 1), such support was not an explicitly funded function of IMOS and AODN should test activities against the cost recovery guidance provided in section 4.1.3. This consideration should extend to stack adopters.

Finding 24. *The Review highlighted the need to consider strategy around a broader play by IMOS and AODN nationally, consistent with Finding 1 and Finding 2, and the likely need to lower the barrier of entry for national data flow.*

4.2.2.3. Process and store

Figure 4 shows the data flow from IMOS providers in more detail. The processing architecture was built upon a "conduit" of processing pipelines, with a core package for ingestion and data handling and additional pipeline-specific processing. The Talend harvester extracted and transformed data/metadata for loading into the PostgreSQL data base to support OGC web services provided by a Geoserver instance, for GeoNetwork and into AWS S3 data storage. AODN acknowledged the challenges of introducing greater generality into core processing and reducing data-/pipeline specific processes.

Figure 4 revealed several special cases in the processing chain, for the Acoustic Animal Tracking sub-facility and for the National Reef Monitoring Network. The first has been an exception since the start
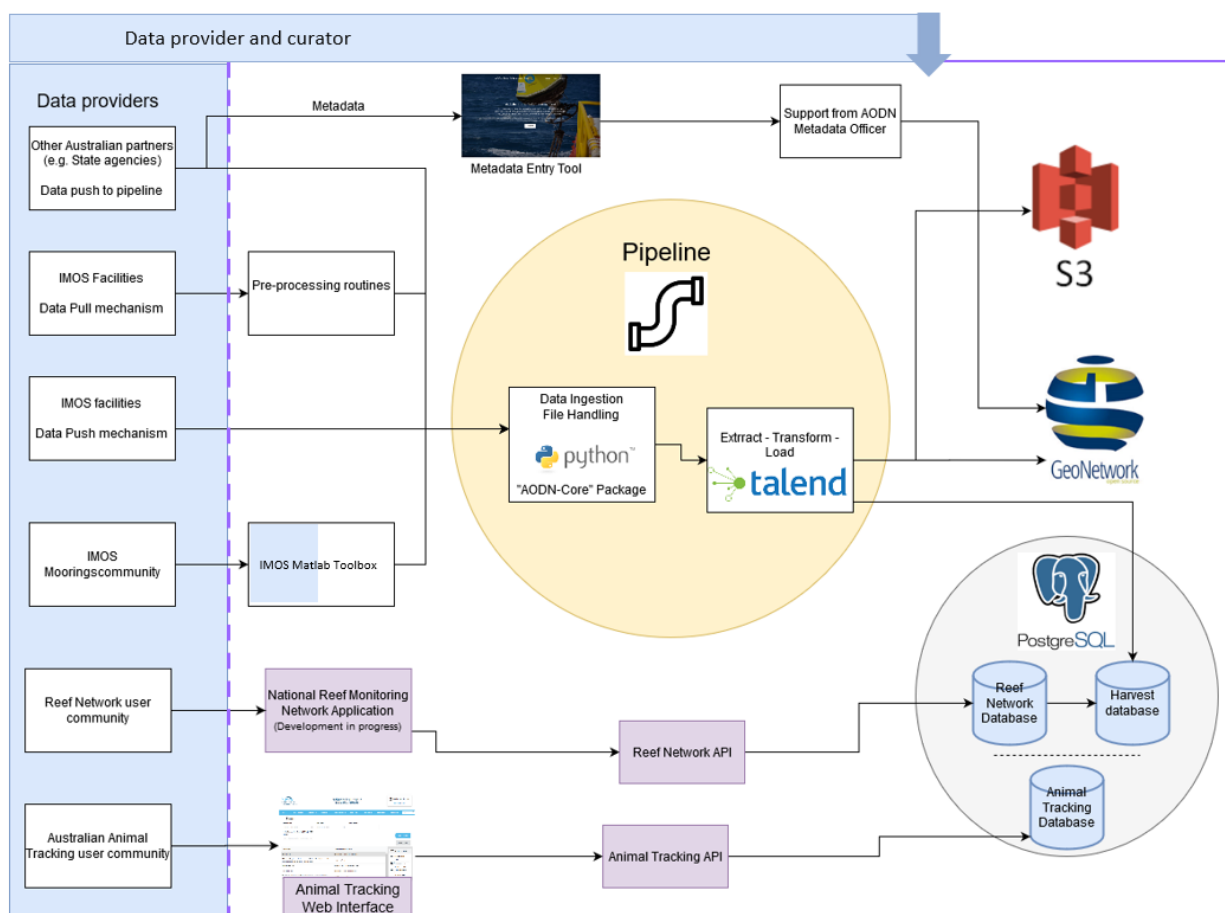
Figure 4. Schematic of the data flow from IMOS providers, through various pipelines to storage (adapted from AODN). The workflows discussed in section 5.1 describe the flows from the facility side (light blue shading) into AODN (the light purple box). In some cases, a facility operator provides processing and storage on behalf of the AODN, reconnecting with AODN at the load stage.

of IMOS, principally to enable a secure and closed data management activity, and a major project to modernize its web interface was currently nearing completion. The National Reef Monitoring Network sub-facility was created in 2018 and a project was underway to integrate its data processing and web services into AODN. Both these projects were discussed in section 3.3.2 and in Attachment I. The management of BGC data (derived from several sub-facilities) was also performed outside the AODN architecture but, in the view of the Review, this was better viewed as an out-sourced pipeline.

Bespoke activities reduced scalability and efficiency since their development cannot take advantage of the core infrastructure and they require dedicated maintenance actions. The policy to support such actions was held at the level of IMOS, not by AODN. Finding 22 was intended to inhibit and dissuade such action in the future. However, the Review concluded the pressure to provide specialist solutions was likely to increase, not decrease. As the Review already identified, AODN clients/users demanded better processes for ingesting and managing biological and ecosystem data, but also

conceded that the standards and examples of best practice were lagging behind the physical/climate domain.

> **Finding 25.** *The Review concluded that bespoke processing, storage and loading solutions should be the option of last resort. Where it was determined that a solution was not possible within the AODN architecture, consideration should be given to developing solutions in the cloud to lessen legacy costs; using skills and expertise of partners to develop prototype pipelines for AODN; setting sunset timelines to ensure bespoke activities received timely review and resetting.*

The Review supported AODN's decision to focus development on Python (the standard language for AODN). The Talend harvester was identified by AODN as a pressure point and they were keen to replace Talend with native Python harvesters. The individual tailoring of harvesting for specific data flows also inhibited scalability and efficiency.

Two smaller points were raised based on consultation and the discussion with AODN. At present, users of AODN data were not notified when a dataset was updated/replaced. There were at least two ramifications. One was that results may not be reproducible – identical download actions performed at different times can give different results, noting that some datasets have been updated five times. Second, users of AODN may finalize work/products ignorant of improvements in the dataset. SQS (Simple Queue Service) was available from Amazon and should be deployed to alleviate this issue.[14]

Second, several respondents noted that artificial intelligence was now being used elsewhere as part of quality assurance suites; a system was taught to identify inconsistencies and peculiarities in data streams. The Review was alerted about several instances where erroneous/poor data escaped from the provider quality control systems; AI may come to the aid of the processing system in the future.

4.2.2.4. Catalogue and publish

Awareness of the catalogue arrangements was low in the community. Users did not understand the purpose and differences between, or in several cases, even the existence of the various Catalogues (Figure 3). Effective searching and downloading demanded greater awareness. The Review concluded the most effective way to accomplish this might be to better expose the Catalogues on the Portal home page. It took the lead Reviewer many weeks to discover that catalogue.aodn.org.au was the home for the (national) AODN Catalogue. Another possibility (without any insight on viability) was for Step 1 of the current Portal to include all metadata holdings, even if they were not searchable or downloadable through the Portal.

AODN advised they had moved from MCP 2.0 to ISO 19115-3 and that this would require a shift to Geonetwork 3; it was far from clear whether this will aid interoperability with partners in the national AODN (even the stack adopters were finding the transition a challenge). The Review concluded Geonetwork 3 was better software and a significant advance for AODN; the User

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[14] The absence of a registered user system and history of downloads does make such services problematic.

Interface was vastly superior and the software itself was much more modular allowing for easier addition of functions/integration with other software. That said, Geonetwork itself only made sense if AODN was intent on sticking with an ISO 19115 metadata paradigm.

The Review was informed of alternative options. Elastic Search provided for geospatial queries [Geo queries | Elasticsearch Reference [7.10] | Elastic] and AWS has built-in functionality that may be more effective. While the Review acknowledged the enthusiasm for open-source, it may make more sense to use the higher-level services offered by the cloud platform rather than AODN building its own 'portable thing'; Rebuild if you have to port elsewhere.

> *Finding 26.* *The AODN should seek greater exposure and understanding of its different catalogues to inform users of the breadth and depth of data accessible and downloadable (perhaps indirectly) from the main Portal.*

> *Finding 27.* *AODN should evaluate options for its Geonetwork as part of its review of AODN architecture. Full consideration should be given to cloud options that may be more cost-effective than AODN-built solutions.*

4.2.2.5. Services

The current architecture offers significant flexibility in service delivery; section 5.2 discusses the user experience in more detail. Finding 26 concluded the architecture and web-interfaces could be changed to give exposure to different AODN data collections. For example, the AODN Portal home page might include:

- Links to the 1-2-3 IMOS++ Portal page/catalogue, as now
- Links to a value-added datasets menu (OceanCurrent, LTSP, and more), which in turn may point to the Portal page above or elsewhere.
- Links to the National catalogue – https://catalogue.aodn.org.au/geonetwork/srv/eng/main.home

The Review discussed next generation search capabilities.

- The EDR API allowed users to query into complex, multiple dimensional datasets using simply 'topology-based' queries, e.g., point, timeseries, area, profile. These topologies were broadly similar to those used in the Observations and Measurements (O&M) Sampling Geometries.
- There was demand for a consistent interface into data holdings that was easier for users to work with.
    o WFS and WCS were notoriously complex and required extensive documentation and reading. The Review heard from multiple correspondents on this issue.
    o The new standards from OGC were based around OpenAPI 'restful' web services. These were more familiar to 'normal' web developers and will be much quicker for people to understand and to write queries. OpenAPI was now widely supported meaning that software clients can be automatically 'bootstrapped' from the service metadata.

- o App developers still needed to understand the data – but all the plumbing was done for them.

Finding 28.   *AODN should research next generation search capabilities as part of its review of architecture and infrastructure. These capabilities may coexist with existing Portal capabilities or, eventually, provide a replacement.*

4.2.2.6.   Summary, discussion

There were significant challenges for AODN architecture including:

- Varied and uneven capabilities of data contributors
- Complexity and diversity of the data types and forms
- The rapidly evolving technology and standards landscape
- Varied end-user requirements and proficiencies
- Uncertainty around the scope and feasibility of a national approach
- The constant search for scalability and efficiency

Even though AODN was relatively young, it showed symptoms of an incremental build cf. planned architecture and planned change. Too busy putting out spot fires to do the fire prevention measures was how one respondent put it. The Review also concluded the AODN were constrained in their ability to make changes. One respondent noted "The architecture of AODN's portal, however, was problematic for much of the community. The AODN architecture was based on parameter-driven faceted searches, which were integral to the fundamental architecture of the portal. This was not optimal for all use-cases". This too presented a significant challenge.

Uncertainty around managing technical debt was also noted by the Review. AODN saw technical debt arising from their inability to ever complete all planned tasks and maintenance. Conceptually, technical debt in software development reflects the accumulated cost of additional rework/maintenance caused by choosing an easy (limited) short-term solution instead of using a better longer-term solution. It was one symptom of poor architecture. AODN have not reviewed their architecture for several years and this was likely contributing to technical debt.

Finding 29.   *AODN should, as a matter of urgency, engage an external IT architect to undertake a detailed assessment of its architecture. Major infrastructure decisions should be delayed until this was done.*

The Review discussed with AODN architecting software for portability. All clouds have the basic services – compute, object store, notification services etc. Best practice was to modularise your code, so the infrastructure plumbing was separate from your business logic. Then software changes needed to port to a new platform were limited to particular parts of the codebase and shouldn't need the business logic to be touched at all. Truly portable code was a pipedream – manual intervention was still needed – but AODN would be better prepared for the future.

Section 2 discussed the challenges of balancing IMOS requirements with those of a national AODN. The present architecture (Figure 3) provided a basis for moving forward. The scope of the present

Review was restricted to IMOS AODN but clearly national AODN and IMOS AODN should be strategically aligned. The TAG had been effective in pushing standards and providing general technical advice on infrastructure and the Review concluded that all would benefit from a more systematic cycle of coordinated work. The cycle would comprise agreement on a set of pilots (trial protocols) that would be tested and analysed by several of the members of the national AODN. TAG members would come together on a cycle of, say, two years to review progress and agree which should be taken forward. This may encourage greater and more rapid convergence of standards. The Review conceded standards have not delivered the interoperability we thought they would – brittle was a term often used – but as discussed previously, the Review concluded they remain a key element for success.

For a national AODN, and arguably for IMOS AODN as well, change management and communicating change associated with the architecture will be important. Already AODN has challenges managing change with its stack adopters; the change to a new ISO standard had ramifications for its partners, just as the decision to support MCP 2.0 did.

Finally, the Review touched on complex queries on big datasets. AODN noted NetCDF was not supported natively by AWS for the versions of GeoServer, THREDDS and ERDDAP that AODN were using. There was poor performance subsetting NetCDF files directly from S3. AODN noted plans to trial cloud optimized gridded data services next year e.g., Zarr/ncZarr. The Review noted there was substantial literature on the opportunities presented by re-architecting to support complex queries on big datasets. For example:

- Analysis ready data. Make your users happy, more productive… | by Theo McCaie | Informatics Lab | Medium
- Representing thousands of NetCDF Files using TileDB | by Peter Killick | Informatics Lab | Dec, 2020 | Medium
- To the cloud and back again: Building a Zarr dataset from bespoke data formats | Informatics Lab (medium.com)

Finding 30.   *AODN must find a more effective solution for querying and subsetting large datasets. The Review supported the plan to investigate cloud optimised gridded data services for its NetCDF data.*

4.2.3.   IT Infrastructure

The discussion of IT structure was restricted, and the Review did not delve into the technical details. The AODN were continually making decisions on infrastructure and the Review found that, in general those decisions appeared to be well-informed and appropriate at the time they were made. However, as discussed in the previous section, the AODN was at a fork in its evolution and critical decisions were looming; the review of its architecture was thus an important step (Finding 29). The challenge was captured well by one of the respondents: "To operate effectively over the long term the AODN needs to carefully identify the niches where its investment will yield value, and not be rendered obsolete by some better opensource project with more momentum 12 months hence! … the core guiding principles need to be carefully thought through and defined so that they ensure delivery of objectives over the long term without being too constraining of the actual path".

4.2.3.1. Amazon Web Services

The migration to AWS began in 2016-17 and was motivated by several factors:

- It provided production data support cf. previous "research" support
- Supported production-grade services
- Cloud native platforms
- "Stack" hosting
- Greater stability and reliability (vast improvement) but increased risk of vendor lock-in
- Improved cost-effectiveness
- Better storage solutions: no bottlenecks; good access control; good security; good disaster recovery
- A developer environment that was the same as for production
- Good software deployment environment (Figure 5)
- Improved facilities for monitoring (Nagios and Sumo Logic)
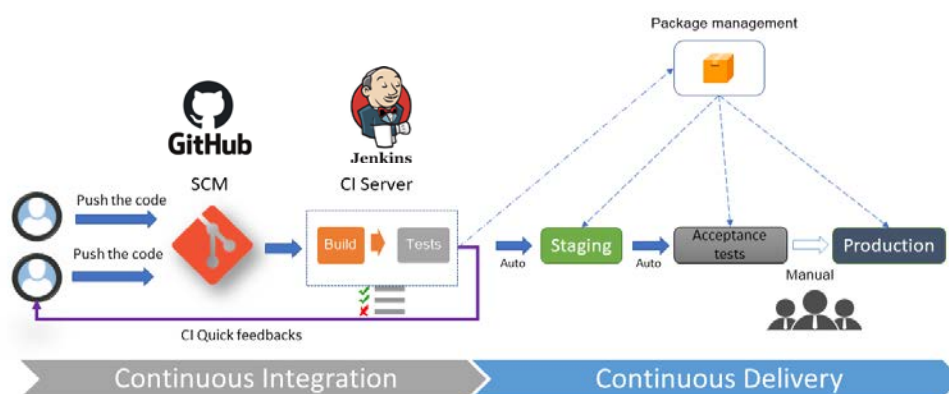
Figure 5. An illustration of the development environment (from AODN).

The Review supported the decision and was not provided any evidence to suggest it should be reversed. Given Amazon was not the only provider of web services, the AODN should always be scanning the market for alternative better providers. AWS were widely used (e.g., in the Met Office) and while there were some risks around proprietary systems and vendor lock-in, those risks appeared no more severe than risks with distributed and/or self-built structures; indeed several of AODN's peers lamented their inability to follow the AODN lead.

The Review (specifically, the technical advisor to the Review from the Met Office) noted opportunities to take further advantage of AWS capability. AODN had a choice between commercial software deployment (particularly from AWS) and AODN open-source builds: the Met Office experience was that sometimes the former can be more cost-effective. The AODN clearly enjoyed working in an open-source environment and did take advantage of developments led by others (e.g., the IOOS NetCDF checker) but the Review encouraged development of principles that could guide decisions around self-builds versus commercial software. As noted in the architecture discussion, bespoke builds may be best done with cloud systems. The Review encouraged a deeper assessment of the offering from AWS, including:

- Making use of AWS Elastic Computing (EC; in effect virtual computing resources) Spot Instances - unused EC2 instances that were available for less than the On-Demand price. Because Spot Instances enable you to request unused EC2 instances at steep discounts, you can lower your Amazon EC2 costs significantly (AODN have explored this option and it is already used where applicable in production).
- Engaging with AWS around their public data program. IMOS and AODN appeared in principle to be a good fit and it could offer cost-effective solutions.
- AWS has an internet-of-things capability.

Finding 31. *The Review supported the AODN use of commercially provided web services and noted they provided security and reliability for the AODN production system. The Review encouraged AODN to examine avenues for more effective exploitation of AWS offerings and to be open to greater use of proprietary systems (cf. self-builds) in the future.*

4.2.3.2. Storage

The storage and manipulation of NetCDF files on the AWS S3 system was one of the few weaknesses in the deployment of AWS solutions (see the previous section for some discussion). The Review discussed some of the trends in the forms used for data storage to improve data access/subsetting times, most of which AODN had some awareness of (please refer to the technical glossary for additional explanation):

- [Dask — Dask documentation](#)
  - Often used in [Pangeo](#) to support distributed parallel data processing
- [TileDB](#) – a new cloud optimised data format.
- [Zarr — zarr 2.6.1](#)

Unidata (the developers of NetCDF) were planning to develop ncZarr next year to improve cloud-optimised storage, addressing the issue of how you manage access to a large number of individual files and make them look like a single dataset. The Met Office Informatics Lab has done some work along these lines[15]. Of particular interest to AODN and IMOS was the improved ability to make data analysis-ready – one of the aspirations of IMOS: datasets that were completely ready to be analysed by a user, where the user doesn't first have to perform data cleaning tasks, or locate missing elements of the dataset, or combine the contents of multiple files in order to be able to use the dataset.

Finding 32. *There were opportunities to improve AODN handling of large (mostly gridded) NetCDF datasets. Given IMOS and AODN were seeking improved forms to improve usability (analysis-ready), there should be a specific call under the New Technology Proving program to develop a prototype for IMOS/AODN.*

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[15] [Representing thousands of NetCDF Files using TileDB](#).

4.2.3.3.   Technical debt

This issue was touched on in the discussion of architecture. AODN were actively auditing and identifying technical debt, as indicated in the table below.

Technical debt – upgrades		2018		2019				2020				2021			
		Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Java		██	██												
Talend				██	██	██	██								
Jenkins					██	██	██	██							
Geonetwork					██	██	██	██	██	██					
Python						██	██								
Chef									██	██	██				
Ubuntu											*██	██	██		
Backups												*██	██		
PostgreSQL														*██	██

Figure 6. AODN identified the 10 highest priority areas of technical debt and developed a schedule for treatment.

Technical debt was not unique to AODN, but they appeared to be accumulating more debt rather than reducing it. AODN identified three key areas of risk for IT infrastructure:

- Back-ups
- Credentials (handling) versus config
- Storing data on S3 (not scalable because AODN depended heavily on List operations, rather than maintaining an index of contents)

The Review identified several strategies to potentially reduce the burden:

- Improved strategic and business planning (sections 3.1, 3.2; Finding 8)
- Reduced tendency toward endless incremental improvements/developments (section 3.3)
- Review of architecture (section 4.2.2; Finding 29).

A key message is to be more strategic and less tactical/technical in the approach to technical debt. With respect to backups and noting that the Review was fully satisfied with the reliability and security of current AWS arrangements, it appeared the agencies who have adopted the AODN stack may offer some level of backup service during an emergency.

Finding 33.   *The arrangements around sharing the AODN stack need some added formality, noting that having one or two partial mirrors and/or alternative technical development sites could be mutually beneficial.*

5. Data Services

5.1. Data Ingestion and Curation

5.1.1. General Background

There were three ways of handling data accessible via the Portal:

1. Data flowing from IMOS facilities with agreed workflows
   - Data and metadata were managed by the AODN team
   - EXCEPT water quality (CSIRO), Argo (global DAC) – in these cases AODN effectively mirrors other data holdings
2. Data flowing from AODN partners with agreed workflows
   - Partners were treated like another IMOS facility
   - Data and metadata were managed by the AODN team
3. Data and web services from AODN partners were used for publication and access via the AODN Portal
   - Data and metadata were managed by the partner organisation.
   - The metadata was harvested in the metadata catalogue powering the AODN Portal

Methods 1 and 2 we refer to as AODN data. Method 3 was in effect a national AODN route for data ingestion and display via the Portal: the partners were doing the ingestion, curation and archiving.[16] Method 1 represented around 50% of the total holdings in the Portal.

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[16] There is another minor exception, and that relates to data provided to AODN for the purposes of formal publication (i.e., a doi is generated). These data are held separately from AODN data.

Figure 4 showed the data flow into AODN and some of the IT components used in translating data into forms that can be published and downloaded through the AODN Portal. The Pipeline was in fact a construct of numerous more specific "ducts" (53 in all), each tailored to a specific type of input, but sharing common approaches and core code which, in principle, provided an efficient scalable approach. The Talend Harvester extracted data and metadata and transformed and loaded the data into storage (78 harvesters in all).

The Matlab Toolbox was developed by AODN in a collaboration with the mooring community and provided a standard of format (NetCDF CF-IMOS), a standard of content, quality control and metadata functionality as data were ingested into the pipeline. Quality control was performed by the mooring community prior to insertion of the data. Maintenance and development of the Toolbox was the responsibility of AODN.

5.1.2. Observation Facilities

There were 11 observation Facilities and around 29 observation sub-facilities (see section 2.2 for a discussion of the "Facility" terminology). There were also 5 facility-equivalent sources of data where the collection of observations was not supported by IMOS but IMOS/AODN offer data ingestion and curation services. All IMOS Facilities provided input to the Review, usually with both a survey and interview (see Attachment F for details). Many of the sub-facilities were also represented, either individually or as part of the Facility interviews.

The established Facilities were generally supportive and positive about the data ingestion and curation process (e.g., "wonderful job", "very effective"). They agreed that the documented IMOS Workflows seemed to work well and that they clearly delineated responsibilities of the Facilities and AODN. Some of the newer sub-facilities remained a work in progress and the National Reef Monitoring Network was going through a difficult scoping, planning and implementation process. Unfortunately, the survey did not allow for separate benchmarking of ingestion but feedback to the Review suggested an overall rating of strong to benchmark.

The Review was impressed with the IMOS Workflows – they were a part of the IMOS/AODN architecture that ensured a robust process for each sub-facility from "planning through data collection to data delivery and public data access". They were the standard operating procedures for IMOS facilities and AODN. There were twenty-five documented workflows and while the Review did not examine them all in detail, all aspects that we would expect to be covered by the workflows were covered, in a level of detail and specificity that provided assurance the system was robust and sustainable. For AODN, it articulated where their responsibilities began and those of the sub-facilities end and supplied a level of assurance that the data flow can continue even if knowledge holders and/or technical experts come and go. They were routinely reviewed and, in the view of this Review, provided a robust process whereby issues and enhancements of elements of the workflows were identified and then considered for AODN prioritisation and scheduling.

> *Finding 34.* *The Review found IMOS Workflows to be well-documented and provided surety around responsibilities through the lifetime of data from instruments into the AODN. The attention to detail was admirable and should withstand changes in technical aspects and in personnel.*

The Facilities inevitably competed for the attention of AODN to address short-term and long-term issues and needed enhancements. Observing technologies and platforms evolved and this had downstream impacts for AODN. The workflows were relatively young and were still undergoing fine-tuning. Considered together, it was then not surprising that there was continual tension at the facility-AODN interface and that demand for ingestion data services outstripped the ability of AODN to serve them.

The Review concluded IMOS and AODN should explore several options for easing such tension. The first, an improved strategic approach, was discussed in section 3.1. The second was to try to avoid incremental ad hoc change which can consume substantial effort in aggregate. All elements of the facility-AODN workflow should go through plan-build-implement-release cycles with versions held fixed until reviewed and a further upgrade/change was scheduled. There should not be an expectation of immediate attention to all issues and needs, no matter how compelling they may appear (urgent matters, where IMOS production was at risk, excepted). The Toolbox was an example of such unending incremental change.

> *Finding 35.*   *AODN should reduce ad hoc incremental change and improvements to the dataset-specific pipeline handlers, Matlab Toolbox, and other technical elements of the workflow in favour of a planned and orderly review and update cycle.*

For the specific case of the Matlab toolbox, while it clearly created efficiencies and improved mooring data flow, it may also have created risks in the chain of accountability and responsibility for quality control.

Finally, IMOS and the Facilities and AODN should develop guidance and policy around expectations for a data ingestion service. In part, this can be drawn from the common threads that run through workflows – who was responsible for quality control and data reprocessing (usually the Facilities); who was responsible for quality assurance (AODN for ingestion); who was responsible for the development of tools (shared); who was responsible for curation (usually AODN). A clear statement and policy would aid new sub-facilities and new sub-facility equivalents to understand potential obligations and expectations and, from an AODN perspective, would regularise the process of developing dataset-specific handlers and tools and ensure bespoke solutions, such as those developed for animal tracking and reef monitoring were the exception, not the rule.

> *Finding 36.*   *Develop guidelines and policy for the IMOS data ingestion process.*

5.1.3.   Curation

Additional commentary arose around other aspects of the organization and integration of data, in addition to those discussed above and in section 4.2.

Legacy datasets. The above sections discussed the pathways for data collected by IMOS or collected by partners and others for which IMOS agreed to provide data ingestion services. For several of the Facilities, observation programs existed prior to IMOS and the establishment of AODN data ingestion services. The Review did not find any policy around whether such data were considered part of IMOS, and so should be ingested and become AODN data, or whether they would be assessed on a

case-by-case basis. The Review was informed some of the pre-IMOS reference station data were made available through the Portal, though perhaps not as AODN data (e.g., the water quality data may be curated at CSIRO). The Review was unaware of any attempt to bring other deep water or coastal mooring data into AODN. Ship-of-opportunity data and early Argo data pre-dated IMOS as well.

> *Finding 37.* *Legacy datasets. IMOS and AODN should develop a position paper on legacy datasets (observations related to Facilities but collected before IMOS came into existence), noting that users might expect that all legacy data could be discoverable, accessible and downloadable through AODN.*

Data Object Identifiers (and other forms of systematic documentation. DOIs provide a method for assigning unique and persistent addresses to data objects/ datasets. Published digital datasets that were required to be uniquely identified and accessible would usually use a DOI, in a similar way to DOIs being used to permanently identify an article or document. DOIs play a key role for accreditation of (static) datasets and otherwise supporting the integrity and provenance of datasets. A systematic approach to the publication of data with DOIs, with supporting scientific and technical documentation, informed users of the data provenance.

There were several instances where AODN supported DOI accreditation, on the basis of its ability to be a secure holder of static (final) datasets, despite the fact it was not permanently funded national infrastructure. The stakeholders involved with such datasets (which may or may not have a connection to IMOS) argued the independence of AODN and its national mandate made it the ideal host. Such hosting was not resource intensive since the datasets were self-describing and held separately from AODN data.

AODN was considering the potential value of assigning DOIs to AODN datasets. The Review does see some advantages, but notes that a far more rigorous versioning process, with published documentation of datasets (ideally peer-reviewed), would be needed to realize value for IMOS and AODN. The Review understood that a dataset referenced by a DOI does not have to be static; the DOI record was updated if the object's content changed significantly. It was OK if the dataset grew incrementally with time, just so long as the curation methods, including quality control remained the same.

There was a small, related issue around publication. Data publishing was the act of releasing data in published form for use by others (making it public, but often with a licencing arrangement). The Australian National Data Service (ANDS, now ARDC) had published some guidance on publishing and reusing data[17]. They noted several types of publication which for AODN included:

1. Releasing information about IMOS/AODN datasets through metadata records, such as practiced by AODN for methods 1 and 2 described in section 5.1.1. In this case, this was the first public release of the data.

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[17] https://www.ands.org.au/working-with-data/publishing-and-reusing-data/publishing

2. Releasing information from metadata records that have been syndicated to AODN by AODN partners or others (e.g., method 3 of section 5.1.1). Strictly speaking, this was republishing since in the majority of the cases the data had already been published.
3. Formally published through data journals or assigned DOIs (as discussed above).

The Review found type 2 releases were often documented and treated as if they were published by AODN. This we found to be problematic since it confused the responsibility and accountability for a product; AODN was uniquely responsible for publishing type 1, but not for type 2. Some stakeholders were also concerned that the results they obtained by accessing the Portal for data syndicated to AODN were missing data from the original publication (we believe this issue was related to the requirements for data to be republished through the AODN Portal). This matter was further complicated by the existence of the national AODN for which all data were in theory type 2 (syndicated), even IMOS data.

> *Finding 38.* *Data publication. IMOS and AODN should develop guidance on data publication, data republication, and formal (documented and/or peer-reviewed) publication so that attributions and responsibilities were clear.*

Finally, the Review identified some issues around the handling of multiple dataset versions drawn from the same observational source; these often arose from reprocessing to include new knowledge, improved quality control methods, improved or updated processes for curation (e.g., changes in metadata keywords) and/or to address errors/shortcomings in the previous versions. The practice in AODN was to replace earlier versions with the latest version; previous versions were archived and available on request, but not findable or accessible through the Portal. That is, earlier versions were unpublished. This became problematic for users who have based research on an earlier version but were (unknowingly) citing a different reprocessed version. It may also be an issue for users who have based advice on a specific version.[18]

The Review was also concerned about the level of documentation on the quality of published data and guidance on how published data should be used. For example, the AODN Catalogue contained information on Argo profilers and other technical details but does not cite any references for quality or other aspects that might affect how data were used. The documentation provided by IMOS and AODN was generally of high quality and it was possible the Reviewer had overlooked relevant reference material published by the Facilities.

> *Finding 39.* *Documentation and versioning. The policy around publishing and handling multiple versions of the same data stream should be reviewed. This review should also consider scientific and technical guidance around the quality of the data and how to use available data.*

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[18] We recognized that IMOS published data with a condition "Data, products and services from IMOS are provided as is without any warranty as to fitness for a particular purpose".

5.1.4. Issues and opportunities

Observation reprocessing. Some facilities have reprocessed and re-published their data multiple times, sometimes simply editing metadata, but in other cases improving QC, introducing new algorithms, and/or addressing errors. For example, glider data have been reprocessed five times. Some correspondents claimed there was resistance to reprocessing even when major issues had been identified. The Reviewer was unable to find policy or guidance on reprocessing, nor whether the standard operating procedures (workflows) were equally applicable to reprocessing. Issues to be considered include:

- Who was responsible for initiating reprocessing – the Facility, AODN or both?
- What were the triggers for reprocessing, and does the schedule depend on the severity of the issue and/or on the additional value perceived to flow from reprocessing?
- Are the changes that result from reprocessing documented and evaluated? There seemed to be an assumption that reprocessed data would be better, but this was not assured, particularly if different individuals were involved in the quality control.
- If the issue was with a single parameter or part of a dataset, were there methods to just update that parameter/part, or must the whole dataset be reprocessed?
- How were users informed?
- Does the funding model for Facilities have a level of reprocessing built into the cost? Similar question for AODN.

Impact of Facilities. There was a level of frustration at the Facility level in terms of data availability. In a nutshell, they worked hard to gather the observations and make them available to AODN in a specified form, with QC, but then received feedback from potential users that the data were too hard to access through the Portal, leading to pressure on the Facility to provide data directly. They also received pressure from IMOS to make their facilities more impactful but perceived obstacles when AODN was the middle person and they were not funded to deliver this value-add (this topic will be picked up again in the following section).

For example, the National Reference Station[19] (NRS) data required a level of expertise to use e.g., knowledge of technical changes at the moorings, and users were required to bring separate data holdings together if they were interested in building time series. Moreover, only a subset of the NRS data was processed through the mooring Matlab Toolbox into AODN; the BGC (water quality) data were quality controlled and curated separately by CSIRO and provided to AODN through metadata harvesting (AODN maintained a (partial) copy of the CSIRO database to allow access via the AODN Portal). There was a separate workflow for the water sampling data.

The division of responsibilities for water quality data was an interesting model – a case where they were working as a national AODN; the "AODN" work was done at a site that had the expertise rather

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[19] As an aside, the Reviewer often confused National Reference Stations and the National Mooring Network terminology! According to https://imos.org.au/facilities/nationalmooringnetwork the first is a sub-facility of the second, which in turn is represented schematically by a mooring. The NRS included additional vessel-based water quality sampling.

than employ a data scientist within AODN. In effect the work (QC, curation, archive) was outsourced; we understood such work was funded as part of the NRS sub-facility not as a separate contract from AODN. To the Review, this seemed a win-win. CPR data were handled in the same way. The contribution from the partner was modest – they provided access to BGC IP and some data management infrastructure. It was hard to see how this could be brought in-house, but perhaps it should formally be treated as part of AODN functionality.

The Reviewer was unsure how a user interested in a particular site (and Maria Island was mentioned many times) goes about getting all the data for that reference station. Moreover, if data existed prior to IMOS, was it discoverable and downloadable? The CSIRO activity appeared to be treated as though it was a part of the AODN.

The long time-series project (LTSP) appeared to have addressed at least part of this need though at the time of writing the Reviewer was unsure how to access/initiate the system. LTSP worked off a set of National Mooring Network data files that have been separately downloaded for each mooring site. Note this project provided an add-on to stitch data together and did not appear to be seamlessly integrated into the portal.

Opportunities for rationalisation. A constant theme through the consultations was that users often preferred to access data through platform specific or thematic sites (e..g., the Argo GDAC; ocean colour data through the NASA Ocean Color website; INSTAC for assembled model-ready physical data). A similar point was made in the RDC Report "A Review of Biological Data Accessibility within the IMOS-AODN Portal"[20]. Some of those correspondents wondered whether IMOS should be investing in AODN capabilities (ingesting, curation, publishing) that replicated capability held elsewhere, or using those specialist facilities to fill a need of the IMOS user community. For example, the Argo GDAC holds all IMOS Argo data and provided excellent capabilities for viewing and downloading data. This was particularly true of visualisation capabilities that were not available on the AODN site.

So then what role should AODN play if any? The strategy for Argo should avoid duplicating effort elsewhere but focus on the value-add for Australian researchers and users: perhaps unique forms of integrated/aggregated data, or multi-observation aggregations/data products. Alternatively, resources could be directed elsewhere.

5.2. User Data Services - Impact and Responsiveness

The impact and responsiveness of user services provided by AODN, including the AODN Portal, dominated the feedback provided to the Review. The Review devoted one of the meetings with AODN to this topic and the many exchanges with the AODN Director and the IMOS Director frequently touched on the topic.

The positive feedback largely reflected on the journey from the state of ocean data management and networks pre IMOS and the position we were in today:

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[20] Compiled by Jason Everett and published by SIMS.

"Generally AODN seems to be following or exceeding best practice for ocean data delivery by international standards … "

"Having all public data available at one location was a significant benefit to the community."

"AODN were demonstrating compelling benefit by facilitating a central repository of data which increases its accessibility to researchers (and also the commercial world)."

"As someone who has conversations with researchers who use a number of portals similar to AODN, I am regularly asked why other data discovery tools cannot have similar functionality to AODN."

The negative comments centred on the AODN Portal, user responsiveness, value-added data products, visualisation and the national role. The latter topics might be classed as unrealised or unrealistic expectations, depending upon your point of view on the AODN remit.

We break this section into three parts:

(1) The AODN Portal, focusing on user services derived from IMOS/AODN-managed data.
(2) Data products and visualisation, two areas that loomed large in feedback and were the subject of debate when considering the remit.
(3) National AODN services, distinguished from (1) by the expectation that the Portal will cover all Australian marine data.

5.2.1. The AODN Portal

In section 3.1.3 we concluded that one of AODN's strategic goals should be:

Goal 2 To make all AODN data (as indicated by Goal 1) discoverable and accessible and provide a user-focused data service/portal that is efficient and effective using content and delivery-based standards.

It was with this goal in mind that the Review approached assessment of the AODN Portal and related user services.

5.2.1.1. AODN and users

Quoting from the IMOS web page on impact "IMOS data was taken up and used thousands of times, creating impact and benefits at local, national and global scales. IMOS measures impact in two ways: through our societal benefit and through our more proximate research infrastructure impact". An implication the Review drew was that the user interface was led and managed at the level of the IMOS Office (as it should be in our view), which raised the question of AODN's orientation to users and the degree to which the services it managed were user driven rather than prescribed. We remarked earlier that the original objective of eMII was to make IMOS data (from its own facilities) discoverable, accessible and downloadable and the current AODN remained heavily aligned to this aim. Yet the user community at large demanded more (from the evidence presented to this Review)

and IMOS's own public vision promised more, to achieve greater penetration and impact in both of the ways IMOS identified. It followed then that the strategy of IMOS should contain goals and actions that were user focussed, and that AODN in turn should be changing from an internally prescribed path to a goal that was user-focused (as reflected in the proposed Goal 2).

This change is not a superficial one but one of great substance and importance for AODN and IMOS, with implications for where effort and resources are to be directed. The Review was surprised to find this change was not already written into IMOS strategy (cf. section 3.1.1 "Context provided by IMOS Strategic Plan") given the previous IMOS Director had made strong statements at the Annual Planning meeting(s)[21]. In practice, the Review identified such change through the support of several New Technology Proving projects, such as "Ocean Data on Demand" (discussed further in 5.2.2). A user-driven approach must be reflected in both IMOS and AODN strategy to achieve a change in both the AODN activities and their relationship with users.

> **Finding 40.**   *Current IMOS and AODN strategy was not sufficiently user-driven and both must be updated to reflect its importance.*

Such a change in strategic direction must be accompanied by specific actions. Respondents commented that AODN may not be close enough to the user and that IMOS and/or AODN might need a better user interface to get advice. Such a function would be different from the help and feedback functions that were currently supported by AODN which tended to have a technical focus.

One obstacle to this change is the fact that users of AODN services were largely anonymous, consistent with Principle 2 on open data (section 4.2.2.1). This Principle has been in place since the start based on an argument that IMOS provided public goods and they should thus be open and accessible to all; registration was regarded as an inhibitor to open access. However, the passage of time and experience elsewhere suggested there was a considerable down-side to such policy. IMOS was limited to general feedback garnered through the Nodes and ad hoc processes, which was not suited to systematically gathering intelligence on user needs, preferences, dislikes, likes, trends, etc.. The AODN information on web hits and downloads was useful but not a substitute.

> **Finding 41.**   *IMOS and AODN needed a form of user registration that would allow intelligence to be gathered on users and usage to inform future IMOS/AODN strategy.*

Such registration should be voluntary in the first instance but could be obligatory for certain data streams such as acoustic animal tracking. Such a change should be accompanied by the establishment of a dedicated capability (a "User Desk") for user relations and feedback, with client relationship skills, and charged with gathering evidence of IMOS user demographics and data and information usage and needs; gathering of use cases should continue as part of that capability. The

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[21] This question was posed during most of the interviews and none of the respondents identified documentation but confirmed separately that the then IMOS Director emphasised that users were demanding data and products that were more usable and user-friendly.

User Desk should be independent of but supported by AODN and complement the activities of the Nodes who were in effect IMOS reference groups.

> *Finding 42.*   *IMOS/AODN needed a dedicated channel (a User Desk) for soliciting user and client feedback and gathering intelligence on user demographics and IMOS data and product usage and future needs. It should be separate from AODN.*

As reported in section 4.1 and elsewhere some respondents found the AODN to be unresponsive to requests, with a tendency to erect fences between their decision making and their clients; this was not a universally held view with others welcoming recent openness and engagement. Lack of strategic planning, transparency and weaknesses in processes, along with excessive demand, contributed to this perception, but the Review also concluded that the technical orientation of skill sets within the current AODN proscribed against effective client and user relations. A user driven AODN would need cultural change as well, to encourage feedback and input to AODN planning and decision processes and enhanced competencies in client relationship management.

> *Finding 43.*   *AODN needed to enhance its skills and competencies in user/client relationship management to ensure all elements of their work could benefit from feedback, as AODN changed from a technical-driven to a user-driven program.*

The effectiveness of Nodes as user forums was beyond the scope of this Review. Some Nodes appeared to have a broad user network, others less so. For AODN, the lack of involvement and engagement by the Nodes was a major shortcoming. The emergence of new facilities/capabilities also pointed to some gaps in those arrangements. For example, the Review consulted with the Climate and Bluewater Node and garnered useful feedback, but there was nothing akin to a Green water or Brown water (coastal) user forum. One stakeholder remarked "AODN would benefit from strengthened processes to determine national priorities particularly those that serve multiple stakeholder types (e.g. scientists, science funders, environmental managers". There does not appear to be an appropriate user forum that AODN could touch into as part of its planning process; the Review concluded that AODN may need to consider an open planning forum (probably virtual) where such engagement, consultation and discussions could take place.

One of AODN's international peers informed the Review that in response to a similar finding they convened a facilitated workshop with users to help set future directions. The use of a non-technical facilitator transcended the user-technical barrier and they received important feedback, e.g., on the need for and type of graphical/visual products.

The Review noted the existence of the Forum for Operational Oceanography[22] and noted that it has achieved at least some of the impact that was being contemplated. It was interesting that this Forum for Operational Oceanography had a major focus on real-time data and information, a facet that was not prominent in the work of the AODN, perhaps because of concern for cutting across the Bureau

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[22] https://www.foo.org.au/operationaloceanography/

of Meteorology program. The Forum for Operational Oceanography motivated the creation of the Surface Waves sub-facility and the delivery of surface waves data by AODN.

The Review made one additional observation around climate users. The Review interviewed the Climate and Bluewater Node and received input from several other users who would identify their domain as climate. A theme that emerged was that the AODN Portal was not the go-to place for climate research or climate applications. One factor was that the AODN Portal specialised in Level 2 data (measurements of ECVs) which then need further processing and analysis to be useful for climate work. The second was that climate manifested on broad regional and global scales, so an Australian centric data service was unlikely to be competitive with global assembly centres, where data were aggregated into global datasets. Even for Australian climate impacts, Level 2 AODN data would need further processing, e.g., to form times series (as targeted in the 2nd goal of the IMOS Strategy). Finally, model products now have a huge impact in climate research and assessment. AODN data were not model ready, so this route to impact had barriers, and the AODN does not serve model products such as ocean reanalyses. One respondent even suggested deprioritising several processing lines which were not delivering any added value over what was achieved elsewhere; this was not an argument against facilities contributing data to climate, but rather about being clinical about the actual return for some activities/investments.

> *Finding 44.*   *AODN/IMOS to consider an annual or biennial user forum or similar mechanism to garner advice and input from Nodes, Facilities and other user groups. This should be convened mid-way through the planning cycle and should be user-oriented, not a technical display.*

One of the innovations in user uptake that the Reviewer was familiar with was that run by the Copernicus Marine Environmental Monitoring Service (CMEMS). CMEMS was an operational ocean information service with an annual budget around twice that of IMOS. It does no data collection but funds thematic data assembly centres and monitoring and forecasting centres. Figure 7 shows the continual strong growth in users and the way that usage was broken down by sectors (much of their user intelligence stems from user registration). To encourage user uptake, they operate a user uptake grants program with an annual budget that was just over 3% of their budget (around $700K in IMOS terms). Calls for proposals were issued through a tender process; individual projects were small (typically ~$40K). The scheme was hugely successful in encouraging user innovation and non-scientific engagement – the majority of the proposals were from the private sector, from small enterprises to big businesses. CMEMS runs training programs to assist users make connections to the data. The Bureau of Meteorology used similar devices in the early days of its Water Program to encourage engagement in its water monitoring and accounting initiatives. The Review encouraged IMOS to consider similar devices to encourage innovation in the application layers and to increase the depth and breadth of its user base.[23]

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[23] The NTP program targets IMOS infrastructure rather than developing the user base.

Finding 45. *The Review found that the lack of an active user uptake program meant that AODN and IMOS were being forced to take on some of that responsibility. IMOS should consider creating a modest user uptake program to foster the development of innovation and user applications.*
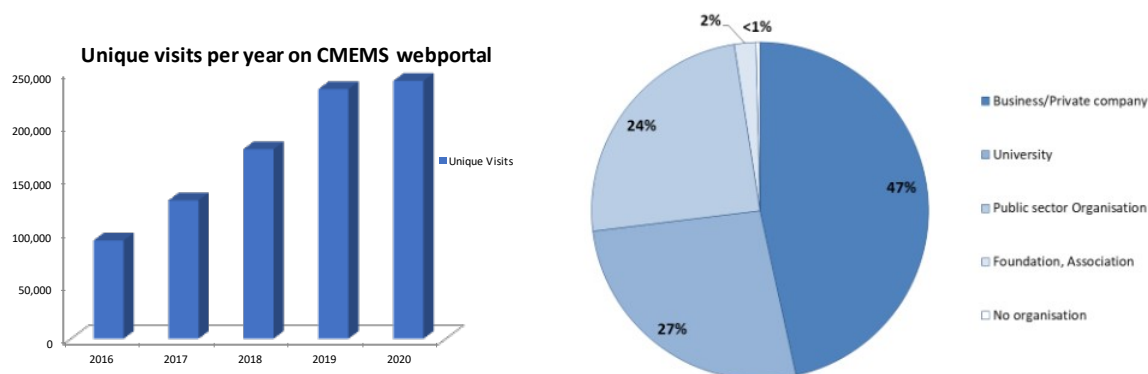
Figure 7. Two illustrations taken from the CMEMS General Assembly, Jan 2021. The left panel (credit P. Bahurel) shows the unique visits to the CMEMS Web Portal over the period 2016-2020. The right panel (credit L. Crosnier) breaks up those users into different sectors.

5.2.1.2. AODN and biological users

While the findings of the previous section applied generally, the biological and ecosystem community presented to the Review as a special case where specific strategy and urgent action were needed.

The Review was briefed on the findings of a study that was commissioned on the launch of the Research Data Cloud "A Review of Biological Data Accessibility within the IMOS-AODN Portal", compiled by Jason Everett (U. QLD). The study used surveys and interviews to understand the way users interacted with and used the Portal and their experiences. The study was deeper and far more detailed than the consultations of the present Review, but at a higher, more general level were completely consistent with the feedback received here. In the discussion that follows we make extensive usage of those findings to complement the evidence gathered by the Review.

The feedback provided to the Review identified several issues. For example:

- "… the physical coastal community who were literate [in the methods of data management] … biologists and other softer sciences worked off collections, images and samples and were not literate in DM… AODN probably has not recognized this difference and broadened its approach to suit."
- "AODN seems quite impenetrable. And so for these users the AODN was not yet delivering the synthesised data products that a biologist or coral ecologist or fisheries scientists could use to improve their science."

    – "The marine biology community has no tolerance for NetCDF … AODN has to move from being a data source to being an information source".

And from the RDC study: "The community highlighted that the AODN portal was very useful if you were trying to discover new data or discover what data was available for a particular date or location. However, it was emphasised that it was often difficult to find data if you did not know exactly what you wanted. Respondents identified satellite data, National Reference Station Samples, Continuous Plankton Recorder data, Animal Tracking and Underwater Imagery from the AUV as the main datasets they come to the AODN to download."

Respondents conceded that best practice for managing and serving biological data continued to evolve rapidly, and compared to the physical/climate community, it was always going to be challenging for AODN to identify enduring solutions, both for the curation and for the presentation of biological data services. Some saw the AODN architecture as fundamental barrier in terms of biological data. Species names were a "variable", not a fixed characteristic. Biological data was stored differently, and different search functionality was required.

The Review concluded that AODN needed strategic guidance to map out a development pathway. AODN were currently being pushed to find short-term solutions as new sub-facilities and new technology arrived, but without a ready model of how to align with best practice. Further consultation has revealed that IMOS, in collaboration with NMSC, have outlined a strategy to move both the observation and data management elements forward (Figure 8). The national framing was important since contributors and data managers came from many different agencies and organisations, including those based on citizen science/observations. The term National Marine Data Landscape was coined to refer to the overarching marine data and collection environment and the then IMOS Director played a key role in pushing this concept.

The Review concluded that such a strategic approach was needed, and specifically for biological data and data services. The Review understood that the Baseline and Monitoring Working Group was due to provide a report in February, but we were unaware of any similar commitment on the TAG side. The RDC report countenanced the creation of a "biological data steering committee" and the Review concluded that something similar was needed to lead this strategic work. Improved strategic advice was essential and should be developed as a matter of urgency.

> *Finding 46.*   *The Review found that a national strategy for agreeing standards for managing marine biological data, and for providing an effective (biological) data service was needed. The AODN/AODN TAG were well placed to lead such work from a technical perspective, but it was deemed essential to engage the marine biological community more broadly, including data providers and data users.*
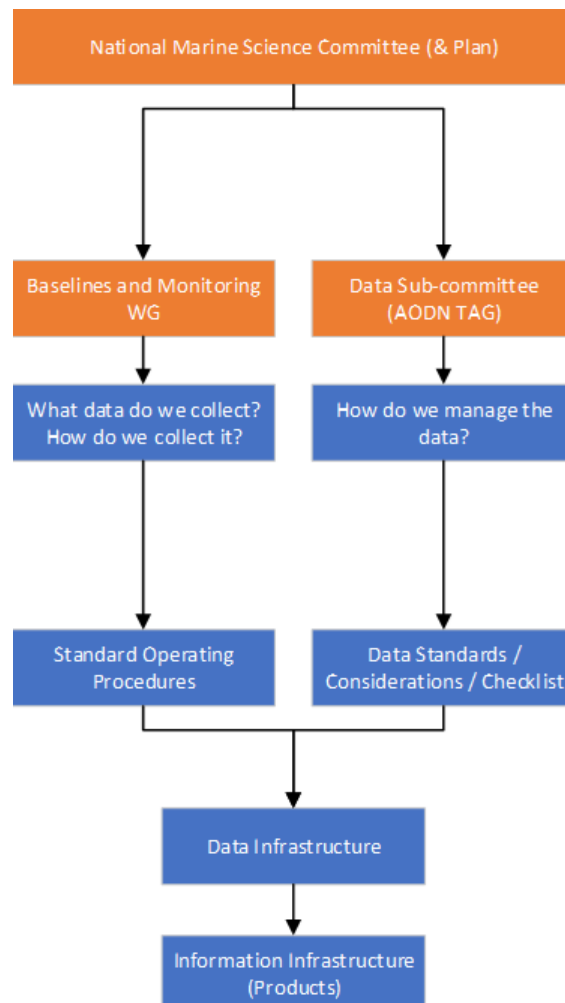
Figure 8. Outline of a strategy for improved measurement and data management programs for biological data (courtesy of P. Walsh, IMAS).

The next two sections will discuss Portal requirements and value-added needs, respectively, in detail but it useful here to draw on the RDC report and make specific findings on some of the required functionality for the biological community.

(1) Data collected at the same location (e.g., National Reference Station biological data) should be findable and downloadable in a single file, regardless of the processing and curation chain. This issue may be addressed in the proposed BGC project.

(2) In addition, it should be possible to simultaneously download relevant environmental data from the mooring.

(3) More generally, it should be possible to isolate and download environmental data when biological data were discovered and downloaded.

(4) It was acknowledged that there may be architectural barriers, so it was important that those issues were considered first (Finding 46).

(5) The User Interface of the AODN Portal could be improved to make it more impactful and intuitive for the biological data community, e.g., easy access to metadata for all national AODN records; notice of new data holdings.

(6) Addition of portal-wide taxonomic searches.

(7) More intuitive vocabularies such as habitat or taxonomy to help users find the data they were looking for.

(8) Provide capabilities for interfacing to "R" (e.g., "R" recognized formats; URLs and APIs).

(9) Develop better data analysis guidance and capabilities (see later discussion).

(10) Creation of temporally averaged satellite chlorophyll products (weekly, monthly, seasonally, annually) which were more in line with biological time-scales (also see later discussion).

(11) More useful imagery tools (the Understanding Marine Imagery project will contribute).

The Findings of the previous section (Finding 42 and Finding 44) were relevant here as well. Biological users need a forum where an understanding of their needs can be developed and considered as part of AODN planning.

The BGC project proposal[24] and the Ocean Data on Demand NTP (now funded) were addressing several of these issues but a full response to the RDC report remained outstanding. As commented earlier, the management of BGC data was an interesting example of partnering between IMOS and a partner (CSIRO) to provide functionality for AODN. Figure 9 showed a re-architected configuration for the management of BGC data, with the new BioViz application (Ocean Data on Demand). The Review believes this was a good first response to some of the issues identified by the biological community.

5.2.1.3.   The Portal

The Portal itself attracted considerable comment, some of which impacted the discussion in section 4.2.2. AODN was regarded as applying good practice, but not necessarily best practice. Other feedback included (most were quotes; some were interpretations of interview input):

− There has been good progress, but we were a long way away from an effective user service
  o Most use a back door to get at data
  o [student users] Need to be escorted through the front door or they will get lost
  o The NTP ocean Discovery [Ocean Data on Demand] project will go a little way to addressing this
  o Lack of real time services, e.g., API for real-time HF data limits applications
− Furthermore, it was predominantly only a repository for "raw" data as opposed to data processed to new variables for publication in papers and reports etc. … There were other marine data servers in Australia that were operating very effectively, e.g., CSIROs Marlin
− … but the discoverability and access using the portal was still non-trivial, and not intuitive.
− As it currently stands it was hard to say that the portal was delivering a national benefit.

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[24] "Development of the IMOS BGC database" Business Case (CSIRO proposal, courtesy Claire Davies, CSIRO)

- ... the success (high impact) of the Blue Water and Climate node contribution to IMOS hasn't been catalysed by AODN at all, but by the nature of the work, and the hard work of the scientists behind the data.
- In most situations people end up bypassing AODN and either contacting the researchers involved in collecting the data, or searching for the same data in other public databases
- A large number of data sets in AODN were not discoverable or available through the AODN Portal, and the format of the portal itself was dated, requiring investment to bring to best practice.
- ... architecture of the portal was dated and does not facilitate replicable searches.
- On the AODN Portal there was this misleading statement "The gateway to Australian marine and climate science data", only it isn't: go through this gate and you only see data that satisfies the AODN Portal restriction.
- I believe the AODN needs to evolve to deliver better data products, and APIs for real time data. What about the ability to serve model output?
- AODN has to move from being a data source to being an information source.
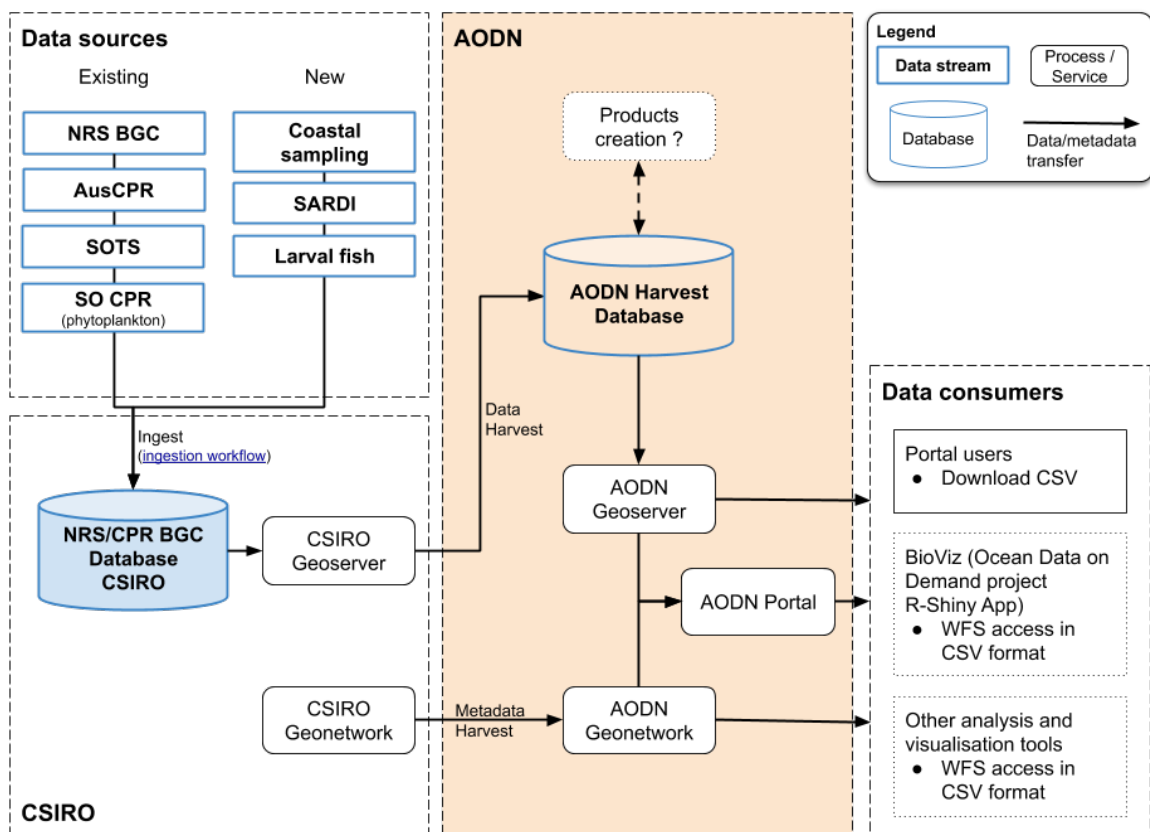
Figure 9. Outline of a proposed workflow of BGC data involving CSIRO and AODN.

The Review understood all such comments to be constructive and targeting the future AODN, not a criticism of the progress to date; as highlighted at the beginning of section 5.2, there was strong

support for progress that has been made by AODN and the AODN Portal. AODN provided the following observations in terms of usage:

- A steady increase over the past three years of the number of users of the AODN Portal from around 600 users per month in December 2017 to 1300 users per month in May 2020.
- A stable number of users of the THREDDS catalogue over the past three years.
- An increase in the number of users of S3 from April 2019.
- An increase in the number of files directly downloaded from S3 in the past two years with significant changes between consecutive months.

One truism for user communities is that they will never, ever be fully satisfied; they demand 5km resolution. You give them 4km, and then they demand 2km. User demands often reflected the benchmarks they have experienced in their particular field, not a reflection of what was feasible and viable by an organization that had multiple masters and multiple demands. Setting priorities among the long wish-list of items demanded good strategy, first at the IMOS level, then at the level of AODN (with a parallel cascade at the national level). Section 3.1 provided guidance.

The second requirement was to truly understand your users, in this case the broad community of researchers and the community developing applications for specific purposes. The earlier section on 'AODN and users' addressed this point. Only those needs that aligned with multiple users should attract support.

Finally, it was about having the right architecture (section 4.2.2) and IT infrastructure (section 4.2.3) upon which user services can be built. All such user requirements needed to pass through a feasibility, viability, cost-effectiveness filter to ensure the most impactful changes were prioritised.

The AODN and IMOS do not have all these elements in place at present but the Findings of this Report, if acted upon, should ensure AODN will make the right choices for future data services. In particular, the AODN must avoid ad hoc and/or spontaneous decisions (responding first to the most influential voice) and always think longer-term.

> *Finding 47.*   *The demand for changes and improvements in the AODN Portal was constant and enduring, and far outreached the ability of AODN to service those requirements. Changes to the Portal should be strategic and systematic; user community driven; feasible and viable within the limitations of architecture and IT infrastructure; and demonstrably impactful.*

The Review discussed the challenges of maintaining up-to-date digital services in an age of rapidly evolving technology (asset lifetimes were typically five years or less) and characterised by a "I want it, and I want it now" culture. AODN were judged by their peers to be "leading" in the field of ocean data service provision but judged only tenable to favourable by many users.

The Portal itself was clearly approaching, or at/passed its use-by date. Even if all the technical deficit identified in section 4.2.3.3 could be addressed (and that would take several years), the Review concluded the Portal would still unlikely be fit for purpose. The impact of the deficiencies in the Portal were ameliorated by guiding users to THREDDS and the S3 data services, and/or by designing

technical work arounds. In the Reviewer's opinion, the issues around searching for and serving biological and ecosystem data, managing and manipulating big data files, and responding to the IMOS strategic need of "turning observations and data into time series of essential marine and coastal variables" appeared beyond the capabilities of the current Portal. The Review identified several potential improvements to the architecture and infrastructure (section 4.2); some of those suggestions may exacerbate interoperability issues within the national AODN, and thus will be difficult decisions. Now was probably the time for IMOS and AODN to act.

> *Finding 48.*   *The Review concluded the AODN Portal was at, or close to its end of life, with growing technical debt and a growing gap between where AODN should be and where it was now. A major refurbishment without substantial change in the architecture would likely not be cost effective or a viable longer-term solution.*

Assuming some of the strategic challenges can be addressed quickly, the Review suggested work on the current Portal should be frozen during the 2021-22 fiscal year and a plan for its replacement developed. There should be less self-build and more off-the-shelf/cloud services incorporated in its replacement. Its design should be user driven.

> *Finding 49.*   *The current Portal should be frozen during the 2021-22 fiscal year and a plan for its replacement developed. There should be less self-build and more off-the-shelf/cloud services incorporated in its replacement. Its design should be user driven.*

MINOR ADDITIONAL REMARKS

The following points were noted without making any Finding:

- It was frustrating that reports/publications testifying to the quality of data were not easily accessible through the Portal or provided with data downloads.
- Users of the Portal reverted to personal contacts or agency web services when they encountered issues, which was disappointing to many in the IMOS community. The Review noted that it would be preferable to proactively manage such issues than let it happen by stealth.
- The AODN Portal should make access to real-time/near-real-time data more prominent (many were unaware that real-time data were available through the Portal – they accessed it using THREDDS or S3).
- AODN should improve notifications of new products (a Tab on the Portal page?) and updates of existing products.
- Earth System Modelling/Science and Ocean Digital Twins were completely frozen out because of the lack of model-ready data.
- A spatial discovery mechanism was needed for the Portal to make it more relevant for Marine Park and other environmental applications.
- It appeared the AusSeabed initiative[25] will address some of the demand for gridded bathymetry data; this initiative was supported by ARDC and several of the IMOS partners,

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[25] http://www.ausseabed.gov.au/

with some involvement from AODC. The Review assumed products would be available on the Portal through the metadata harvesting process of national AODN.

- A modest data viewing capability would significantly enhance the user experience. Several respondents noted that ERDDAP had the potential to provide some capability (e.g., it can provide json files for "R").
- The 1-2-3 approach made sense when you were tracking down a particular data stream. Once you wished to cut across (think of it as jumping across the tree branches in THREDDS), then you struggled and you were often left with a huge number of datasets.
- The AODN Portal can sometimes be slow, particularly if you were subsetting in a way that was not native (e.g., constructing time series from gridded satellite data).

5.2.2. Data products and visualisation

The Review found a common theme running through feedback concerning value-added data services. Much of the data that were served by AODN were at Level 2 (for reference, the Table below shows the normal definition of Levels); that is, the raw data have been turned into values of essential ocean variables, but otherwise not further processed (averaged, interpolated, interpreted, analysed, assembled, …). Some facilities provided gridded products at Level 3 (e.g., gridded ocean colour data). Level 2 data were generally accessible to experienced scientists, so long as they were in a familiar form, but non-specialists (including undergraduates and ECRs) and general users often thirsted for more user-friendly and analysis-ready data.

Level 1	Unpacked, reformatted instrumental data, with all supplemental information to be used in subsequent processing appended.
Level 2	Retrieved ocean variables (e.g., temperature, ocean wave height) at the same resolution and location as the level 1 source data.
Level 3	Data or retrieved ocean variables which have been spatially and/or temporally re-sampled. Such re-sampling may include averaging, interpolation and compositing.
Level 4	Model output or results from analyses; derived variables (e.g., mixed layer depth) that were not directly measured by the instruments, but were derived from these measurements.

The Review concluded that the topic of value-added products and visualisation justified a dedicated Review Report sub-section and an explicit reference in the draft AODN Goals:

Goal 5. To contribute as appropriate to IMOS plans for value-added data aggregations and products and for visualisation of data and products.

There were several messages in the framing of this goal, all driven by feedback from stakeholders. First the Review identified a significant gap in the portfolio or work supported, a gap that was well known to IMOS but not explicitly drawn out in IMOS strategy in the opinion of the Review; somewhat paradoxically, it did appear in the remit considered by the Review. The NTPs were in part a response to this need. Second, the Review found that AODN, in its present form at least should engage in the development of such products but not necessarily take the lead, or even play a significant role. The key role of AODN was to ensure that its infrastructure and data services were fit

for the purpose of developing such products, The Review concluded that over time users would gravitate toward these products and away from Level 2 data.

Value-added data products were emphasised by many stakeholders, with OceanCurrent often cited as the exemplar. Susan Wijffels (WHOI/CSIRO) presented the following schematic at the 2019 OceanObs Conference. The key take home message was that investment was focused mostly on the front end of the cycle with more modest investment around data provision and gridded products (including models). Expert synthesis and value-added data products were the least supported part of the cycle.
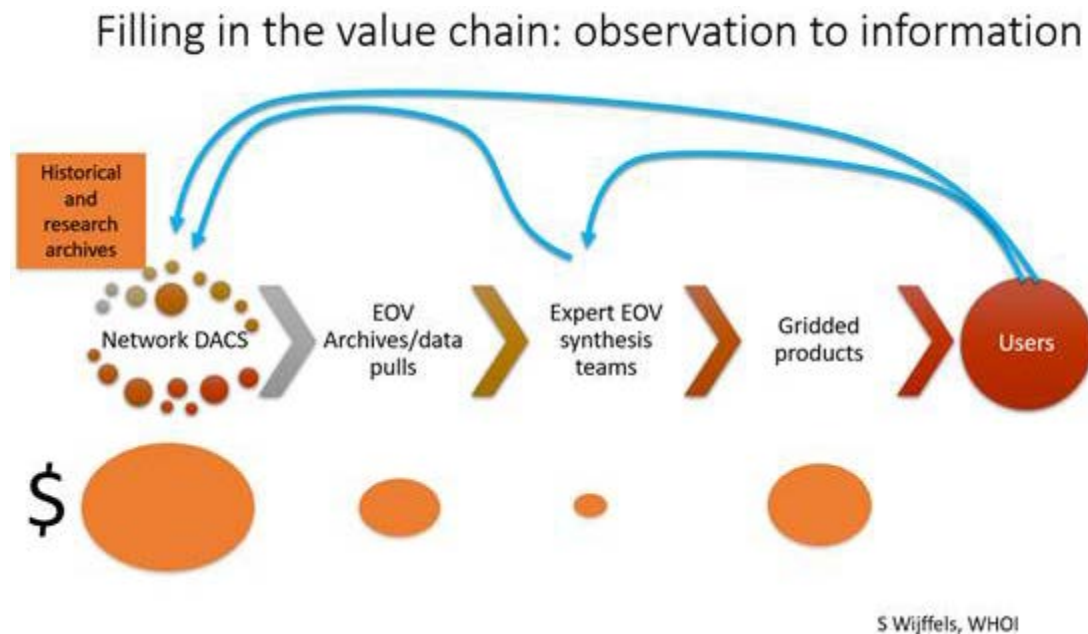
Figure 10. A schematic illustrating the uneven investment during the lifecycle of data (credit, S. Wijffels).

How should IMOS/AODN promote the development of the needed products? One route was to support/create sub-facilities specialising in Level 3 products, such as OceanCurrent (for mapped fields and ocean currents and sea level) and variable time series from moorings (the LTSP project).

A second route was to provide APIs so that third parties could develop their own applications, abstracted from the detail of the Portal and internal storage of AODN. This has been done for the S3/WPS but its biggest user seemed to have been AODN itself.

Another route was to deploy a service layer that does some of the work for the user, such as ERDDAP. It removed the need to understand the form or structure of the data – it learned it once for everyone – but then provided a more generic interface for users to retrieve the information they want. The user can also take advantage of the visualisation tools provided by ERDDAP to see and use data.

Finally, one could promote/facilitate the development of IMOS/AODN applications, as discussed earlier in section 5.2.1.1, in a manner analogous to the way mobile phone companies and others

have facilitated the development of apps for their devices. IMOS/AODN defines the interface standards – how to plug in and extract information, something that AODN was already good at, and then 'the market' does the work for you. Section 5.2.1.1 covered one way to prime the user community to engage in this work.

Respondents listed several cases where apps have been developed to exploit AODN data, e.g. overlaying HF currents on other information. OceanCurrent was in effect an application layer, but it also contributed product to the AODN store. The Ocean Data on Demand initiative, which may become a facility if fully successful, will achieve this value add in a way suited to production.

Visualisation of data also arose often in stakeholder feedback. AODN noted that gridded data were visualised in the portal, but feedback suggested the Portal fell well short of meeting the requirement. For example, some users preferred OceanCurrent to the AODN Portal because it provided visualisation of the profiles and maps for context. Users looked for guidance in the form of graphics/visuals to aid them in searching for the right data, cf. downloading many files, writing programs to extract the data, and then plot it, only to find it was not what they wanted.

Another way of enabling visualisation was to provide interfaces usable by "R" programmers (section 5.2.1.2 discussed this in the context of biological data). "R" appeared to be the open-source analogue of Matlab, and enabled scientists and students to perform basic tasks such as analysing and visualising data. This may be a relatively simple way to enable more effective use and uptake of AODN data, to achieve impact.

Another form of demand for graphics/visualisation was provided by a fisheries user who simply wanted a plot of data to include with a report. This user did not have the skills to negotiate a way through the Portal to download the relevant data and then plot it: the graphic/visual was the desired end product.

In developing strategy around this area, a co-design and co-development model might be appropriate. For some applications, it may be appropriate for AODN to host production, in others it might be hosted elsewhere. In terms of risk, external hosting might be preferred.

> *Finding 50.* *The AODN Portal does not have the capability to manipulate or visualise data to meet a major demand from users for value-added products. IMOS needed to develop a specific strategy to meet this demand. AODN can contribute through co-design and co-development, as appropriate, but should make its focus the provision of effective data services to underpin this development. The strategy should focus on facilitation rather than a new set of facilities within IMOS.*

One astute stakeholder offered the observation that, if AODN was able to rearchitect their data services (user-responsive services) and also promote, and in parts support a line of value-added data products and graphics/visualisation, then AODN would in effect be making the transition from an ocean data network to an ocean information network.

5.2.3. National AODN data services

Stakeholders strongly supported the concept of a national Australian Ocean Data Network (see section 2 for discussion). Some even deemed it to be a success: "In my mind the most successful implementation of a 'working federated data eco system' as part of NCRIS, or even globally". The Review concluded the AODN must continue to promote and contribute to its national counterpart, as represented by the draft goal:

Goal 7. To promote and contribute to a national interoperable network of marine and coastal data services.

As noted in section 1, this was a forward-looking Review examining the IMOS AODN program and was not intended as an assessment of the nationally sponsored broader initiative. However, as IMOS AODN played a leading national role, it was relevant to assess the effectiveness of that role and provide advice on how this broader national initiative might evolve.

Figure 11 shows the present landscape for marine and coastal data in Australia, in effect the landscape for the National AODN. IMOS/AODN made considerable contributions but the landscape as a whole was much larger than AODN.
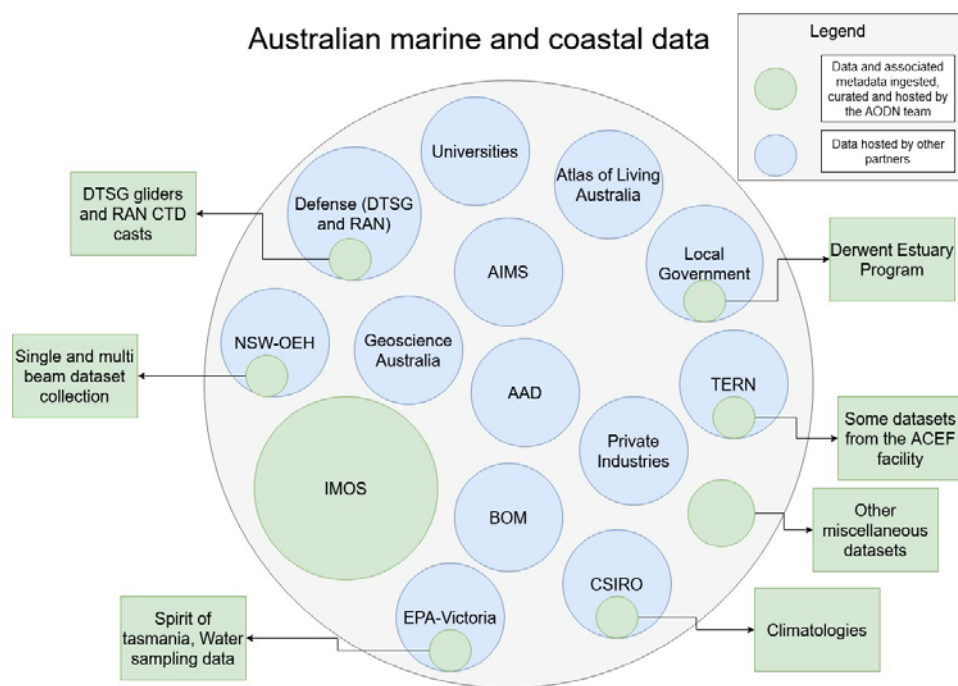
Figure 11. Schematic of the Australian marine data landscape (courtesy AODN).

The national AODN conceived in 2005 (see Box 2) was a coalition of individual agency ocean/marine data services that determined, where practical, to use standards-based metadata and coordinated approaches for curation and publication of data. The original national AODN web page connected to agency data services through hyperlinks, but there was also some effort to consolidate available metadata. There was no ability to search for data across agencies or to download data. Progress was

slow – there was little dedicated effort for the national AODN. No data were transferred to the host of the AODN.

Box 1.   Timeline of the national Australian Ocean Data Network

C. 2001
- RAN host the Australian Oceanographic Data Centre (AODC)
- Commonwealth agencies launch the AODC Joint Facility
- The TAG migrated to NMSC
- Some joint work on common approaches to standards and metadata

2005
- The concept of an Australian Ocean Data Network launched by the AODC JF, led by RAN
- Commitment to harmonise metadata standards.

2006
- IMOS created with eMII.

2009
- Launch of IMOS 1-2-3 Portal by eMII

2011
- IMOS takes over as lead for national AODN.
- eMII invests in development of standards (community marine profile, vocabularies, …

2015
- AODN Portal launched (separate from IMOS Portal) with capability to discover and download some non-IMOS holdings.
- AODN highlighted in National Marine Science Plan 2015-2025

2016
- eMII renamed AODN (capability and program).
- National AODN still recognized by NMSC and operates TAG.

2018
- Transition to single AODN Portal

2020
- IMOS convene Review of IMOS AODN

Under IMOS leadership, AODN shifted to a federated model, with IMOS as the lead and responsible for the development and maintenance of national AODN infrastructure and some other cross-agency functions. Metadata was harvested from participating agencies and, where agency metadata conformed with IMOS/AODN Portal requirements, data can be searched and downloaded from the AODN Portal. IMOS also varied its scope to manage data collected by a few smaller partners and curated some other data/data products that were considered strategically important for IMOS and AODN. Diversity in metadata standards, particularly those needed for faceted searches, limited the ability of the federated model. The AODN does not ingest publicly funded data in general, nor was it able to make such data accessible to the broad national and international community (first article of the remit discussed in section 2).

What should the future look like? No stakeholder believed it was practical, or even desirable for the AODN to hold/curate all national ocean and marine data, though many believed it should take more

responsibility for ensuring publicly funded observations were properly curated and published where no other mechanism existed. This broader role was not yet funded, but partially cost-recovered data services may provide a part solution (only the incremental cost charged). Priorities, including for important historical data would need to be developed. The Review also recognized that IMOS partners and contributors to the national AODN were not funded to support national AODN, meaning it was likely to remain a venture based on best endeavours and good will until Governments agreed to make it a national priority.

The discussion of architecture and infrastructure (section 4.2) suggested that wider adoption of ISO 19115-3 and/or exploitation of emerging standards from OGC based around the OpenAPI 'restful' web services approach might deliver greater interoperability between national AODN partners and enable more data to be found and downloaded through the AODN Portal (section 5.2.1 discussed options for the future of the AODN Portal). It seemed unlikely the AODN Portal would ever have sufficient generality and functionality to serve all data requirements, so some aspects of the coalition/federated model may need to be kept. That is, AODN partners would continue to provide specific data services for users while AODN would attempt to meet general needs.

The previous section found that IMOS AODN needed to evolve toward a more user-centric data service model and that more focus needed to be placed on the provision of higher-level data products and visualisations. The national AODN would likely need to evolve in a similar way.

> *Finding 51.*   *The AODN should continue to promote and contribute to a national interoperable network of marine and coastal data services with the AODN Portal providing a window to national data holdings. The AODN should also seek further opportunities to ingest, curate and publish publicly funded ocean and coastal observations more generally.*

6. Benchmarking

The Review sought benchmark advice from all respondents as well as drawing conclusions from the evidence provided to the Review. AODN provided self-assessment in selected areas. In hindsight, the Review survey was not structured well to capture benchmark feedback; an attempt to keep the survey compact and easy to respond to led to areas being merged such as "Capability and capacity", and the impacts of ingestion and outward data services were considered as one. The AODN input was better organised. The interviews did allow some opportunity to unpack the responses but only in a qualitative sense.

AODN SELF ASSESSMENT

Table 3 provides the AODN self-assessment on how they benchmarked themselves against their peers. In general, they were conservative, not finding they were "benchmark" in any specific area; most ratings were in the good but not strong range (favourable). They did not provide a rating against processes (strategy, planning).

Consistent with the findings of the Review, they recognized challenges in the Project initiation stage. Their history on project execution was probably not strong, but as the analysis in Attachment I showed, they were trending to strong on the basis of improved PM. Their ratings against architecture were also consistent with the Review findings; there remained considerable work to do (see Recommendation 6, Recommendation 7 below). They were well placed in terms of infrastructure, but their view on scalability may be overly optimistic. Like the Review, they found they were in a strong position for data ingestion. They used the FAIR Principles as a basis for rating the data services, which probably painted an overly optimistic picture, particularly in terms of user-facing issues.

STAKEHOLDER INPUT

Many respondents were uncomfortable rating AODN processes, strategy and remit, mostly because of lack of familiarity with AODN internal mechanisms. Many were also not familiar with AODN IT infrastructure so this rating was predominantly reflecting staff capability. For impacts most correspondents focused on AODN output (the AODN Portal). Table 4 provides a synopsis of the main findings. Respondents rated them favourable in terms of process, but with the caveat that few were familiar with planning or business processes. Capability was rated favourable-to- strong, but it mostly did not take account of internal architecture and infrastructure. The favourable rating for impact was dominated by views on the ingestion process (strong or better) and the perception AODN could do better on services (tenable to favourable).

Table 3. AODN benchmark self-assessment. Their reporting followed the meeting arrangements but used the same guidance on the benchmark (weak, tenable, favourable, strong, benchmark) as outlined in the example survey provided at Attachment G.

Project Element	Rating
Initiation	Tenable
Planning	Favourable
Execution	Strong
Monitoring and Control	Strong
Closure	Favourable
Architecture Element	**Rating**
Principles and Guidelines	Tenable
Framework (Planning)	Weak
Systems Element	**Rating**
Technology Stack	Favourable
Quality	Favourable
Scalability	Favourable
Security	Favourable
DevOps	Strong
Software Processes	Favourable
Data Ingestion Element	**Rating**
Extract	Favourable
Transform	Strong
Load	Strong
Service: FAIR principles	**Rating**
Findable	Favourable
Accessible	Strong
Interoperable	Favourable
Reusable	Favourable

Table 4. Benchmark ratings provided by the survey. See Attachment G for guidance on the ratings. DNR = Did not rate.

Rating	Process	Capability, Capacity	Impact
DNR	13	7	3
Tenable	3	1	5
Tenable-Favourable	0	1	0
Favourable	5	6	8
Favourable-Strong	2	2	3
Strong	8	13	11
Benchmark	2	3	3
Average	3.50	3.71	3.45
Review	Tenable-Favourable	Favourable	Tenable-Favourable/Strong

REVIEW FINDINGS

The Review placed considerable weight around the views expressed by peers. International peers were uniform in their praise of the AODN, probably around the strong range across all categories. They envied the ability of AODN to begin the build without a long history or legacies to complicate the design. International peers found AODN engaged well, particularly in areas like standards and vocabularies, but noted their low profile in IODE. The Review noted than none of the international peers were organized like AODN, and each operated with different demands and policies. Some peers immediately recognized the challenge of being user-driven and responsive. Other peers, particularly in Europe, identified with the challenges of a federated model but none provided a model that could or should be followed by AODN.

National peers took a rather different and more critical view, but all the while recognizing that AODN had made a significant difference nationally and should be commended for their progress. When asked about exemplars for different aspects of AODN's work, the Reviewer was often referred to their own systems. The Review noted that national peers tended to have specialised responsibilities and thus it should not be surprising that in their own areas of specialisation, they should perform as well or better than AODN. National peers often drew attention to the lack of transparency and strategic planning and to the tension points with their own agencies. National peers were most critical of the AODN Portal and concluded it was not really responding to the current national need.

The Review concluded that AODN needed to strengthen its strategic processes and recalibrate its planning and business processes; some aspects were in a favourable position, others were just tenable. The Review concluded the capability and capacity of the Team were well placed but noted significant issues around staff turnover and accessing the right skills for the AODN of the future (favourable-strong). There were greater challenges in terms of architecture and infrastructure (tenable-to-favourable). AODN were in a strong position with respect to data ingestion, but tenable to favourable across data service delivery.

> *Finding 52.* *AODN was rated favourable or better across most of the areas assessed by the Review. In the key area of data ingestion, the review found AODN to be strong, but for data services, however, they rated less favourably. AODN people and infrastructure compared well against their papers, but for architecture they are facing significant challenges.*

7. Synthesis and Recommendations

The Review was charged with providing a forward-looking assessment and evaluation of the IMOS AODN program and processes to ensure the AODN facilitated efficient and optimised data access and delivery of derived products to Australia's marine science community now and into the future. The Review was asked to consider the current and future capability (i.e., skills, infrastructure, partnerships) of the AODN program.

The Review conducted surveys and interviews of stakeholders and peers and interviewed key personnel from the IMOS Office and the AODN. The AODN presented its response to the terms of reference through a series of detailed presentations and meetings. The Review found the input of AODN to be informative and constructive and wishes to acknowledge the significant contributions of the AODN Management Team and other AODN staff to the Review.

The Review focused on

- Remit, scope and structure
- strategy and planning
- business processes
- human resources (capability, capacity)
- IT infrastructure, including architecture
- data ingestion
- data and product services

The synthesis and recommendations are organised accordingly, with additional comments around benchmarking (7.9) and the specific areas targeted by the terms of reference (7.10).

7.1. Remit, scope and structure

The Review concluded IMOS and its national partners need to clarify and distinguish between governance and activities of the national ocean data network and those of the IMOS group and program known as AODN (Finding 1). There should be a shared understanding of the organisational arrangements involving AODN, the IMOS Office, the AODN TAG, NMSC and STAC (Finding 2, Finding 6) and of the status of intergovernmental representation (Finding 3). The remit of the AODN should be adjusted accordingly (Finding 5). The organisational arrangement should clearly distinguish the roles of different IMOS entities (Finding 4, Finding 7); the term facility was now being applied more broadly than in the past.

> ***Recommendation 1***   *IMOS should provide added clarity around national provisions for ocean data management, in consultation with the NMSC, and adjust terms of reference, organisational arrangements and scope accordingly. A clear statement on the remit of AODN should be agreed.*

7.2. Strategy and planning

The Review found AODN had weak strategic planning and that this weakness impacted most areas of its work. The Review further found that the expected flow-down from national and IMOS planning, and upward influence from AODN was fractured and inconsistent (Finding 8). Stakeholders advised that IMOS and AODN needed to have a user-driven approach and that strategy and policy needed to be reset to reflect that (Finding 9). The planning cycle for AODN should be revised, with strategy guiding prioritisation, and far greater transparency, and engagement with stakeholders early in the planning cycle, prior to the IMOS annual planning meeting. Plans should include indicative schedules for the out-years (Finding 10).

> **Recommendation 2**   *The AODN should develop a strategic plan, reflecting the high-level strategy of the IMOS Plan, but also identifying aims and priorities to guide AODN plans. Stakeholders should be engaged in this process. The Annual Business Planning cycle should be restructured to allow greater external engagement and increased transparency around priorities.*

7.3. AODN business processes.

The Review found that the project management methodologies adopted by the AODN represent best practice and should be retained and strengthened (Finding 11). However, implementation of project planning in isolation has caused significant issues during roll out including (a) disconnect with Governing Board decisions, (b) poor recognition and buy-in from clients (mostly Facilities), (c) an over-crowded pipeline of work, and (d) excessive time and documentation devoted to the planning process. The AODN Project Management methodology (PRINCE2) was in wide use in Australia and IMOS should support IMOS-wide buy-in, but in a so-called Lite form that is more appropriate for small-to-medium projects (less than $1M; Finding 11).

An analysis of recent projects revealed multiple failings in the process; the coincident roll-out of Project Management was one contributing factor. The review concluded that IMOS should rethink its decision-making process for projects heavy in IT and involving AODN. The business case presented to the Governing Board should align with the expectations of Project Management, with clarity on the products/functionality required, and with a level of specificity that allows sound cost estimation (Finding 13). IMOS should also examine co-investment and costing arrangements for IT infrastructure projects (Finding 14).

> **Recommendation 3**   *IMOS should adopt Project Management methodologies to support project planning and execution of IT projects, harmonised with governing body decision making processes as appropriate. Project Management implementation should be right-sized for the size and complexity of projects and AODN should reset its processes accordingly.*

7.4. Human resources (capability, capacity)

The Review could not find any persuasive evidence that AODN was either over- or under-resourced relative to objectives of IMOS but concluded it was under-resourced for the grander national objectives. AODN base funding included both core funding for operations and maintenance, and

funding for project builds (refurbishment of assets and new builds). This was not unusual for organisations with significant assets and relatively short life cycles (5-10 years). This base funding was supplemented with finite term funding for specific projects. The base project funding was largely at the discretion of the AODN Director, while additional funding was determined by the Governing Board and the IMOS Office. Added clarity was needed to ensure IMOS and AODN had clear line of sight on investment returns (bang-for-buck; Finding 15, Finding 16). Weaknesses in planning and priority setting contributed to a perception in AODN and IMOS generally that AODN was under resource pressure. The expansion in IMOS facilities from 2018 undoubtedly added pressure and indirectly impacted core activities (delays, technical debt).

> **Recommendation 4**   *The review does not provide any recommendation for a change in base funding but does recommend adjustments to process so there is a clear line of sight for (a) base funded operations and maintenance (core), (b) base project capacity, and (c) fixed-term project funding.*

The Review found AODN staff enjoyed good levels of respect professionally and a rewarding work environment. Pressures from both the core and project pipelines manifested as increased stress on capability and capacity and a tendency for AODN to push back when faced with new demands (Finding 17). Several capability gaps were identified and AODN needs improved capability planning to better manage skill demands (Finding 18).

The Review also concluded that the short-term contracting arrangements for AODN staff contributed to high staff turn-over and disruption to both the core and project tasks. These arrangements were a mismatch for the IMOS long-term strategy for AODN and national data activities (Finding 19). Greater use of outsourcing could alleviate AODN specialist skill needs (Finding 20).

> **Recommendation 5**   *AODN should put in place capability planning processes, including options for out-sourcing when special needs arise. IMOS should explore options for more secure staffing arrangements consistent with the IMOS long-term strategy for AODN, to improve position competitiveness and to mitigate high staff turn-over rates.*

7.5. Architecture

The Review recognized AODN successfully delivered a diversity of data in self-documenting architecture-independent open formats with widely used metadata standards and that this represented a significant achievement (Finding 21).

The Review clarified data flows into AODN (AODN data) and found several potential avenues to improve the architecture of the ingestion system, including consideration of recent changes in standards and the potential of systems available through the cloud. The Review also concluded IMOS, in consultation with IMOS partners, should improve guidance for data providers concerning (i) standards adopted for interface; (ii) general policy for quality control responsibilities to reside with the data providers; (iii) conditions to be satisfied for data providers to be IMOS-approved and supported data flows; and (iv) the evolution toward a broader national data curation and publication role (Finding 22, Finding 23, Finding 24).

The Review concluded the pipeline architecture did promote scalability and efficiency but AODN identified several potential barriers, including the harvesting of data and metadata and technical debt (Finding 24). The Review found bespoke ingestion, processing, loading and publication/web service solutions proscribed against scalability, efficiency and agility in the architecture. If such solutions were deemed necessary by IMOS, cloud solutions should be preferred with sunset agreements to reduce legacy risks and costs (Finding 25).

> **Recommendation 6**   *IMOS and AODN should reset policy and guidance for existing and potential data providers so that (a) required data and metadata standards were clear, (b) differentiated responsibilities and accountabilities were clear, and (c) integration into the AODN architecture was strongly preferred.*

The Review found that the publishing and web services architecture was offering the user community diverse opportunities to discover, access and download data. The Reviewed noted greater exposure and understanding of the different AODN catalogues would enhance this impact (Finding 26). Some aspects of the web services architecture were dated and the Review encouraged AODN to evaluate options, including those offered by the cloud cf. AODN-built solutions (Finding 27, Finding 28) to inform users of the breadth and depth of data accessible and downloadable (perhaps indirectly) from the main Portal.

The Review found there was an urgent need for review and resetting of its architecture, and that major infrastructure decisions and builds should be delayed until this was done (Finding 29).

> **Recommendation 7**   *AODN should undertake a review and reset of its architecture as a matter of urgency, with scalability and efficiency included in the criteria, and an overall aim of greater flexibility to introduce new technologies. The resetting should include greater consideration of cloud solutions where appropriate.*

7.6.   IT infrastructure

The Review supported the AODN use of commercially provided web services and noted they provided additional security and reliability for the AODN production systems. The Review noted several potential avenues for more effective exploitation of cloud offerings and greater use of proprietary systems (cf. self-builds) in the future (Finding 31). The Review noted an urgent need to improve handling of large (mostly gridded) NetCDF datasets and a need to find a more effective solution for querying and subsetting such datasets. The Review supported AODN plans to investigate cloud optimised gridded data services but also encouraged IMOS/AODN to seek improved forms to improve usability of data (e.g., analysis-ready), either through a tender or a partnership (e.g., under the NTP program) (Finding 31, Finding 32).

> **Recommendation 8**   *AODN should assign high-priority to the need to find efficient and effective IT solutions for handling large datasets including querying and subsetting capabilities.*

AODN struggled to manage technical debt, for a variety of reasons. The situation does not appear to be improving. Improved strategy, better planning and renewed architecture will help. The

arrangements around sharing the AODN stack need some added formality to ensure this was not contributing to the burden (Finding 33).

7.7. Data ingestion

The Review found that the ingestion and curation of IMOS observation facility data was generally effective and most stakeholders rated it as strong or better. The Review found AODN Workflows for data ingestion were well-documented and provided surety around responsibilities through the lifetime of data from instruments into the AODN. The attention to detail was appropriate and admirable and should make the process stable and capable of managing disruptions such as changes in technology or personnel (Finding 34).

The Review identified an expectation of continuous incremental improvement and enhancement of the ingestion infrastructure (dataset-specific pipeline handlers, Matlab Toolbox, etc.). The Review found this to be unrealistic and likely a contributing factor to AODN over-commitment. AODN should reduce ad hoc incremental change and improvements in favour of a planned and orderly review and update cycle (Finding 35).

The success of AODN has led to demand for access to its ingestion and curation system. IMOS has supported selected external data holdings to be managed as AODN data, but the Review found unmet demand, particularly around academic and other public data. Moreover, it appeared that some of the new facilities were unprepared for the rigours and demands of AODN data management. The Review found it would be helpful for AODN/IMOS to develop guidelines and policy for the IMOS data ingestion services (Finding 36). This guideline should also consider a position on legacy datasets, specifically observations related to Facilities but collected before IMOS came into existence. Users clearly expected such data to be presented in a unified way through the Portal, even if the form of the legacy data proscribed against it being made discoverable, accessible and downloadable through AODN (Finding 37).

The Review found ambiguity in the accountability and responsibility for publication. For IMOS generated data the situation was clear, but for third party AODN data and republishing of national AODN partner data, the situation needed added clarity (Finding 38).

The Review found that the policy and practices around handling multiple versions of the same data stream and publication (including formal publication through the use of digital object identifiers) should be reviewed. This review should also consider scientific and technical guidance materials around the quality of the data and how to use available data (Finding 39).

> **Recommendation 9**   *Policy and guidance should be developed for the observation-AODN interface to make clear the differentiated responsibilities for quality assurance and quality control, the high standards on metadata and data, and the enduring responsibilities of data curation and publication that were borne by AODN.*

7.8. Data and product delivery services

The Review devoted considerable time to assessment of AODN data and product services, principally because of the amount of feedback received on the topic. There were differences of view, with some respondents focusing on the huge advances made by IMOS AODN, which the Review recognized, while others focused on what should or could be done to improve data services. Opinions on the impact of AODN data delivery services also varied; the Review considered them to be favourable (good, but not strong).

> ***Recommendation 10*** *IMOS, with input from AODN, should review and update strategy to ensure greater focus on users and usability with identified actions to achieve such change.*

The Review found that despite recent attention being given to the demand for value added products, the present IMOS and AODN strategy was not sufficiently user-driven and user-focused and must be updated (Finding 40).

The Review also considered the way AODN managed the relationship with users and identified a number of shortcomings, some of which derive from the lack of user registration, a process that would allow IMOS and AODN to gather intelligence on users and usage to inform future IMOS/AODN strategy. Such a process need not and should not hinder the commitment to open data (Finding 41). The Review found IMOS/AODN needed a dedicated channel (a User Desk) for soliciting user and client feedback and gathering intelligence on user demographics and IMOS data and product usage and future needs. It should be separate from AODN (Finding 42).

The Review found AODN needed to enhance its skills and competencies in user/client relationship management to ensure a culture that was user focused and that all elements of their work benefited from user feedback (Finding 43). As part of this process of change, AODN/IMOS should consider an annual or biennial user forum or similar mechanism to garner advice and input from Nodes, Facilities and other user groups. This should be convened mid-way through the planning cycle to properly inform planning and should be user-oriented (use cases, user needs, etc.), not a technical display (Finding 44).

The Review found that the lack of an active user uptake program meant that AODN and IMOS were being forced to push data and data products rather have having the pathway to impact facilitated by a community of value-adders. IMOS should consider creating a modest user uptake program to foster the development of innovation and user applications (Finding 45).

> ***Recommendation 11*** *AODN and IMOS should enhance capabilities and functionality for users including consideration of i) user registration, (ii) the creation of a User Desk, (iii) enhanced capability and capacity for user relationship management, (iv) a dedicated user forum, and (v) a system of user uptake grants.*

The Review found that a national strategy for agreeing standards for managing marine biological data, and for providing an effective (biological) data service was needed. The AODN/AODN TAG were well placed to lead such work from a technical perspective, but it was deemed essential to engage

the marine biological community more broadly, including data providers and data users. The NMSC Monitoring and Baseline Working Group could facilitate such involvement (Finding 46).

The demand for changes and improvements in the AODN Portal was constant and enduring, and far outreached the ability of AODN to service those requirements. Changes to the Portal should be strategic and systematic; user community driven; feasible and viable within the limitations of architecture and IT infrastructure; and demonstrably impactful (Finding 47).

The present AODN Portal does not have the capability to manipulate or visualise data to meet a major demand from users for value-added products and visual/graphic material. IMOS needed to develop a specific strategy to meet this demand. AODN can contribute through co-design and co-development, as appropriate, but should make its focus the provision of effective data services to underpin this development. It was the opinion of this Review that the strategy should focus on facilitation rather than a new set of facilities within IMOS (Finding 50).

> **Recommendation 12** *IMOS and AODN, with its partners, should develop and agree a strategy specifically for (a) management and servicing of biological and ecosystem data, and (b) for developing value-added data and data products.*

The Review concluded the AODN Portal was at, or close to its end of life, with growing technical debt and a growing gap between where AODN should be and where it was now. Such a finding should not be a surprise in a world of rapidly changing standards and technology. A major refurbishment without substantial change in the architecture would likely not be cost effective or a viable longer-term solution (Finding 48). The current Portal should be frozen during the 2021-22 fiscal year and a plan for its replacement developed. The Review concluded there should be less self-build and more off-the-shelf/cloud services incorporated into its replacement. Its design should be user driven (Finding 49).

With respect to national AODN data services the Review concluded that AODN should continue to promote and contribute to a national interoperable network of marine and coastal data services with the AODN Portal providing a window to national data holdings. The AODN should also seek further opportunities to ingest, curate and publish national publicly funded ocean and coastal observations more generally (Finding 51).

> **Recommendation 13** *The AODN Portal, in both its national and IMOS manifestations should be replaced, to take advantage of new technology and to better position it to respond to future user needs.*

7.9. Benchmarking

Benchmark advice was provided through surveys and interview and by AODN through self-assessment.   AODN was rated favourable but trending to strong across its planning and business processes; as experience was gained and improvements were made with both strategic planning and Project Management it should become strong. The AODN Team was strong in some parts but had gaps in others, particularly when referenced against future AODN requirements. The Team was well-respected by its peers. Position security and staff turn-over weighed heavily on the assessment.

AODN architecture was not well positioned and does require urgent technical review and resetting. IT infrastructure was generally well-positioned. Data ingestion processes were rated as strong, with several attracting benchmark ratings from peers. Data services, however, were viewed less favourably, weighed down by expectation (perhaps unreasonably so) and limitations arising from the architecture. AODN leadership on national approaches to services was welcomed but many challenges remained (Finding 52).

7.10. Areas to make findings on

The Terms of Reference for the Review identified six specific areas for attention by the Review. The Table below lists the findings and recommendations relevant to those areas (for convenience, all findings and recommendations are listed in Attachment J).

1. Consideration of the current approach and advice on any IT systems, operations, workflows or platforms that may increase efficiency;	Finding 2, 4 and 7; Recommendations 1, 2 Findings 23, 25, 28, 31 & 32; Recommendations 7,8
2. Business and project planning processes and their efficacy;	Findings 8-14; Recommendations 1, 2 and 3.
3. The composition of skills, experience and agility within the current team including resourcing (e.g. number of FTE required);	Findings 15-20; Recommendations 4 and 5.
4. Functionality of the current AODN Portal and all other data delivery infrastructure (including user feedback) and any recommended improvements;	Finds 40-51; Recommendations 10, 11, 12 and 13.
5. Ability of the current processes and infrastructure to scale to meet current and future needs (e.g., grow to serve expanding data delivery needs in the community);	Findings 21-33; Recommendations 6, 7 and 8 Finds 34-39; Recommendation 9
6. Recommendations for any capability changes required to ensure the AODN can deliver on its remit now and into the future.	Findings 16-20; Recommendation 5

Attachment A.   Statement of Work

External Review of the Australian Ocean Data Network - Terms of Reference

Purpose

This is a forward-looking review examining the AODN program and processes to ensure the AODN facilitates efficient and optimised data access and delivery of derived products to Australia's marine science community now and into the future. The review needs to consider the current and future capability (i.e. skills, infrastructure, partnerships) of the AODN program.

Background

The Australian Ocean Data Network (AODN) is an interoperable online network of marine and climate data resources. The AODN is a Facility within the Integrated Marine Observing System (IMOS) and as such hosts data produced by other IMOS Facilities. In addition, where possible, data sets from other research programs or marine research organisations are also ingested, hosted and delivered by the AODN. A number of research agencies and programs work with and contribute to the AODN.

All data hosted by the IMOS AODN is made freely available to the public and is designed to align with FAIR principles (Findable, Accessible, Interoperable and Reusable). The data hosted by AODN covers numerous variables collected from a suite of platforms (e.g. ships, moorings, autonomous vehicles), with a range of data types (e.g. profile data, trajectory data, timeseries data and gridded data) and spanning from the deep ocean to coastal regions. Data holdings include biological, biogeochemical, atmospheric and physical variables which are delivered to the research and other communities for their use.

The AODN team is tasked with a broad remit including:

- Populating the AODN with publicly funded data and making this accessible to a broad national and international community, particularly data from IMOS-based research infrastructure,
- Implementing FAIR (Findable, Accessible, Interoperable, Reusable) data principles,
- Developing and maintaining tools to ingest, visualise and analyse data using project management methodologies (e.g. business analysis, project communication, functional specification development and framework design),
- Encouraging and developing a culture of data sharing across the marine science community of Australia,
- Developing and applying content and delivery-based standards for marine data and metadata to support Australia's science, education, environmental management and policy needs,
- Maintaining robust and reliable infrastructure and professional data services,
- Developing data management procedures and workflows that result in the improvement of data quality, its accessibility and re-usability,
- Specifying, developing and deploying advanced e-services as part of a broader-based institutional Virtual Research Environment to facilitate individual and collaborative research.

Review Scope

The review of the Australian Ocean Data Network (AODN) should:

I.   Assess the AODN business model against the remit of the program to ensure the AODN can continue core business while also having the capability to support and deliver new/additional activities, priorities and data sets (i.e. ability to scale to future needs), derived data products and has the ability to

maintain archived data for ceased activities. This review should consider the capability, effectiveness, efficiency and agility of the current program and operations. **[1]**[26]

II.   Provide recommendations on improvements to current practices and how the program can be configured to meet current and future needs. **[2]**

The review scope should include:

a   Examination of the AODN remit. **[3]**

b   Examination of current IT systems and processes for maintenance and expansion of the existing AODN data infrastructure. Including consideration of fitness of purpose of existing systems and determining if there are alternative systems/processes that could increase efficiency and reduce the amount of effort directed to maintenance. **[4]**

c   Comparison of infrastructure and performance to programs with similar remit, including data delivery, infrastructure development and maintenance, project delivery (e.g. software or system development projects) and derived data product delivery. **[5]**

d   Examination of current processes for business case development and project planning to determine: 1) if there are ways to streamline while maintaining the capacity to manage internal and external expectations, and 2) whether current planning processes accurately predict project development timelines. **[6]**

e   Assess if the AODN capability is adequate and appropriate to fulfil and deliver the remit, strategy and overall AODN program as well as IMOS strategic directions. **[7]**

f   Examination of data accessibility and channels of use and uptake (e.g. via the AODN Portal vs THREDDS) relative to the functionality of the AODN Portal and the needs of the research community. **[8]**

g   Stakeholder feedback of AODN ease of access, issues and delivery. **[9]**

In undertaking this review, regard should be given to:

- IMOS principles for delivering freely available and accessible data derived from a sustained ocean observing program. These data must meet quality assurance, metadata and data standards to promote use and interoperability.
    a. The current AODN program of work and workload relative to current capability, resourcing levels and any potential cost efficiencies in adopting different approaches or models.
    b. The status of the existing underlying infrastructure and systems and their potential impact on service delivery.

Stakeholder Consultation

Within the scope of the review, targeted consultation should be undertaken with the following*:

- AODN management and staff
- IMOS Office staff
- IMOS Facility members
- Institutions who contribute data to the AODN (including partners with limited data management capabilities (e.g. NSW-OEH, EPA-VIC), partners using the AODN Portal stack to publish dataset collections (e.g. IMAS, NIWA) and partners from larger organisations and existing infrastructures (e.g. CSIRO, AAD, AIMS, GA)
- Researchers and users requiring data from the AODN infrastructure (AODN Portal, AWS Services, THREDDS, web interfaces and applications)

*The IMOS Office can provide some contact points

Review Content Areas

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[26] The **[bracketed]** numbers have been added by the Reviewer for reference within the Report.

In analysing the above considerations and developing recommendations, the review team should incorporate findings on the following:

Area a.   Consideration of the current approach and advice on any IT systems, operations, workflows or platforms that may increase efficiency;

Area b.   Business and project planning processes and their efficacy;

Area c.   The composition of skills, experience and agility within the current team including resourcing (e.g. number of FTE required);

Area d.   Functionality of the current AODN Portal and all other data delivery infrastructure (including user feedback) and any recommended improvements;

Area e.   Ability of the current processes and infrastructure to scale to meet current and future needs (e.g. grow to serve expanding data delivery needs in the community);

Area f.   Recommendations for any capability changes required to ensure the AODN can deliver on its remit now and into the future.

Timing and requirements

The review requires a report to the IMOS Office outlining the key findings and conclusions. Where possible this should include recommendations for action. A report must be provided to the IMOS Office by March 2021.

Attachment B.   Biographies of Reviewers

Dr Neville Smith FTSE was the Deputy Director (Research and Systems) at the Bureau of Meteorology before retiring in 2014 and was previously the Chief Scientist and head of the Bureau of Meteorology Research Centre. His responsibilities included the Bureau's observations networks, communications and computing infrastructure, supercomputing facilities, research and the ionospheric prediction service. He was elected to the Australian Academy of Technological Sciences and Engineering in 2005. Dr Smith has been a leader in the ocean and climate modelling and observations area for 30 years and was involved with the establishment of several innovative observing and ocean forecasting initiatives, most of which were involved in ocean data management. He was the Australian Representative to the Intergovernmental Oceanographic Commission from 2003-2011 and vice-Chairperson of the Commission 2005-2009. He was the Bureau of Meteorology representative to the AODC Joint Facility Board 2004-5 and on the IMOS Governing Board until 2012. Since retirement from the Bureau, he has co-Chaired the Tropical Pacific Observing System 2020 Project Steering Committee (2015-2019); Chaired of the Australian Marine National Facility Scientific (now Research) Advisory Committee (2015-2021); and co-Chaired the Copernicus Marine Environmental Monitoring System since 2015. In 2020 he completed a review of "Support Provided to Global and Regional Ocean Observing Systems" for Global Ocean Observing System Office of the Intergovernmental Oceanographic Commission.

Mr Jeremy Tandy

Jeremy Tandy is a UK Met Office Principal Fellow, positions created to recognize exceptional performance in the Met Office. Jeremy has a background in software engineering with expertise in IT infrastructure and architecture. He played a leading role in the development of the new World Meteorological Organization Information System, the System that connects all National Meteorological and Hydrological Services and regions together for data exchange, management and processing, advocating and leading progressive approaches to technology and standards. Within the Met Office Jeremy plays a leading role in ensuring that the Met Office continue to be recognised as a world leader in adopting new technology approaches.

Attachment C. Technical Glossary

Term	EXPLANATION
API	Application Programming Interface (API) is a software intermediary that allows two applications to talk to each other. APIs are used internally to access data on AWS, and by external clients to access data and information held by AODN.
Architecture	Data architecture is a set of principles, standards, guidelines and/or rules that govern how data are acquired, curated, arranged, preserved, integrated, and interfaced to users.
AWS	Amazon Web Services (AWS) provide on-demand cloud computing platforms and services to individuals, companies, and governments, on a metered pay-as-you-go basis
Bootstrap	Bootstrapping describes a process that automatically loads and executes commands – building from the ground up.
Celery	Celery is an open-source asynchronous task queue or job queue which is based on distributed message passing. While it supports scheduling, its focus is on operations in real time.
Curation	Data curation is the organization and integration of data collected from various sources.
Dask	Dask is a flexible library for parallel computing in Python.
Data Portal	A data portal is a web application, website, or page of a website that is a gateway to data from different sources, organized under subsets or categories to make it simple for the users of the site to find.
DeVL	AODN Data Enhanced Virtual Laboratory
DevOps	The combination of practices and tools that rapidly deliver applications and services.
DOI	Digital Object Identifiers (DOIs) – or Data Object Identifiers – are a system for assigning unique addresses/identifiers for digital data objects. They are intended to provide a persistent link to the data/dataset location on the internet.
Elastic Beanstalk	AWS Elastic Beanstalk is an easy-to-use service for deploying and scaling web applications and services developed with Java, .NET, PHP, Node.js, Python, Ruby, Go, and Docker on familiar servers such as Apache, Nginx, Passenger, and IIS.
eMII	IMOS eMarine Information Infrastructure
Faceted search	Faceted search uses product or content features (e.g., geospatial, temporal, variable, platform, …) as criteria to refine their search results.
FAIR	The FAIR Data Principles (Findable, Accessible, Interoperable, Reusable)
Federated	A federated body of data is data joined by a single set of metadata, but with the individual data remaining under the control of its owner. In the context of AODN, ocean data from different organisations are joined together through metadata held by AODN to give a federated data collection.
GeoNetwork	GeoNetwork is a catalogue application to register resources, with a focus on geospatial datasets and services. It provides powerful metadata editing and search functions as well as an embedded interactive web map viewer.

GeoServer	GeoServer is an open-source server written in Java that allows users to share, process and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards.
ISO/TS 19115 (19115-3)	ISO/TS 19115-3:2016 describes the procedure used to generate XML schema from ISO (International Standards organisation) geographic information conceptual models related to metadata.
MCP 2.0	Marine Community Profile Version 2.0 (superseded by adoption of ISO 19115-3).
Nagios	Nagios is a host service (AWS) monitoring.
NetCDF	NetCDF (Network Common Data Form) is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented (gridded) scientific data.
OGC	The Open Geospatial Consortium (OGC), an international voluntary consensus standards organization, originated in 1994 to collaborate in a consensus process encouraging development and implementation of open standards for geospatial content and services, sensor web and Internet of Things, GIS data processing and data sharing.
OPENAPI	The OpenAPI Specification is a specification for machine-readable interface files for describing, producing, consuming, and visualizing RESTful web services.
Pangeo	Pangeo is a community working collaboratively to develop software and infrastructure to enable Big Data geoscience research in cloud and high-performance-computing environments.
PM	Project Management
Portal	A data portal is a list of datasets with pointers to how those datasets can be accessed. It is usually a combination of web applications, website, or pages of a website and is intended to make it simple for the users of the site to find and download the data they want.
Postgres/PostgreSQL	PostgreSQL is a powerful, open source relational database system.
PRINCE2	PRINCE2 is a process-based structured project management methodology that has been widely adopted around the world, including in Australia.
Publication	Data publication is the action of publicly releasing data in a form suitable for use by the broader community.
Python	Python is an interpreted, high-level and general-purpose programming language. Python's design philosophy emphasizes code readability and can be implemented on most systems.
Quality Assurance	Quality assurance focuses on process: ensuring that all the steps involved in data collection and data ingestion (from Facility to storage) have been followed and are operative. The lead will usually be provided by AODN (e.g., the workflows).
Quality Control	QC monitors and verifies that the ocean data meets the defined quality standards. It is a reactive process (detection). The lead will normally reside with the Facilities.
RabbitMQ	RabbitMQ is message-queueing software, also known as a message broker or queue manager.
RESTful (API)	REST stands for representational state transfer and a REST API (also known as RESTful API) is an API that conforms to the constraints of REST architectural style and allows for interaction with RESTful web services.

Scrum	Scrum is an agile project management methodology or framework used primarily for software development projects with the goal of delivering new software capability every 2-4 weeks.
SQS	Amazon Simple Queue Service (Amazon SQS) offers a secure, durable, and available hosted queue that lets you integrate and decouple distributed software systems and components.
Squidle	Squidle is a web-based framework that aims to facilitate the exploration, management and annotation of marine imagery.
Sumo Logic	Sumo Logic provides cloud log management for application and IT log Data"
Talend Harvester	Talend provides enterprise software solutions for big data, data integration, data management, master data management, data quality, data preparation and enterprise application integration. In AODN it is used for harvesting data and metadata.
Technical debt	Conceptually, technical debt in software development reflects the accumulated cost of additional rework/maintenance caused by choosing a limited short-term solution instead of a better longer-term solution. AODN use the term more generally to refer to the backlog of needed work.
TileDB	TileDB is an open-source and cloud-native storage engine for chunked, compressed, multi-dimensional arrays. It introduces a universal data format, general enough for all application domains, and with built-in data versioning. It offers many APIs and data science tool integrations.
WCS	OGC Web Coverage Service Interface Standard (WCS) defines Web-based retrieval of coverages – that is, digital geospatial information representing space/time-varying phenomena.
WFS	OGC Web Feature Service (WFS) Interface Standard provides an interface allowing requests for geographical features across the web using platform-independent calls. One can think of geographical features as the "source code" behind a map, whereas the WMS interface or online tiled mapping portals like Google Maps return only an image, which end-users cannot edit or spatially analyze.
WMS	A Web Map Service (WMS) is a standard protocol developed by the Open Geospatial Consortium in 1999 for serving georeferenced map images over the Internet. These images are typically produced by a map server from data provided by a GIS database
WPS	The OGC Web Processing Service (WPS) Interface Standard provides rules for standardizing inputs and outputs (requests and responses) for invoking geospatial processing services, such as polygon overlay, as a web service.

Attachment D. List of acronyms

Acronym	Definition
AAD	Australian Antarctic Division
AATAMS	Australian Animal Tagging and Monitoring System
ABP	Annual Business Plan
AI	Artificial intelligence
AIMS	Australian Institute of Marine Science
ALA	Atlas of Living Australia
AMSA	Australian Maritime Safety Authority
ANDS	Australian National Data Service
AODC	Australian Oceanographic Data Center
AODN	Australian Ocean Data Network
API	Application Programmer Interface
ARDC	Australian Research Data Commons
ATF	Animal Tracking Facility
ATRC	Australian Temperate Reef Collaboration
AUV	Autonomous Underwater Vehicle
AWS	Amazon Web Services
BGC	Biogeochemistry/biogeochemical
BODC	British Oceanographic Data Centre
BPA	Bioplatforms Australia
CFO	Chief Financial Officer
CIO	Chief Information Officer
CMEMS	Copernicus Marine Environmental Monitoring Service
COVID	Coronavirus disease (COVID-19)
CPR	Continuous Plankton Recorder
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DAC	Data assembly center
DAWE	Department of Agriculture, Water and the Environment
DCAT	Data Catalog Vocabulary
DeVL	AODN Data Enhanced Virtual Laboratory
DM	Data Management
DOI	Digital Object Identifier
EC	European Commission
ECRs	ESDIS Consolidated Requirements System
ECV	Essential Climate Variable
EDR	Environmental Data Retrieval (EDR) API
EFT	Effective full-time staff
eMII	IMOS eMarine Information Infrastructure
EOV	Essential Ocean Variable
EPA	Environmental Protection Agency (US)
ERDDAP	Environmental Research Division Data Access Program
FAIR	Findable, Accessible, Interoperable, Reusable
FRDC	Fisheries Research and Development Corporation
FTE	Full-time equivalent staff

FY	Fiscal Year
GA	Geoscience Australia
GBRF	Great Barrier Reef Foundation
GDAC	Global data assembly center
GEOINT	Geospatial intelligence
GIS	Geographic Information System
HF	High-frequency (radar); also a Facility of IMOS
ICT	Information and Communication Technology
IFREMER	Institut Français de Recherché pour l'Exploitation de la Mer
IFremer	Institut Français de Recherché pour l'Exploitation de la Mer
IIS	Internet Information Services
IMAS	University of Tasmania Institute for Marine and Antarctic Studies
IMOS	Integrated Marine Observing System
INSTAC	In situ Thematic Assembly Centre of CMEMS
IOC	Intergovernmental Oceanographic Commission of UNESCO
IODE	International Oceanographic Data and Information Exchange
IOOS	US Integrated Ocean Observing System
IP	Implementation Plan
ISO	International Organization for Standardization
IT	Information Technology
JCOMM	Joint WMO-IOC Technical Commission on Oceanography and Marine Meterology
LTSP	Long time-series products project
MCP	Marine Community Profile
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information [NOAA]
NCI	National Computing Infrastructure (NCRIS)
NCRIS	National Collaborative Research Infrastructure Strategy
NESP2	National Environmental Science Program
NET	National Environmental Satellite, Data, and Information Service
NetCDF	Network Common Data Form
NIWA	New Zealand National Institute of Water and Atmospheric Research
NMN	IMOS National Mooring Network Facility
NMSC	National Marine Science Committee
NODC	National Oceanographic Data Center (NOAA)
NRMN	National Reef Monitoring Network (now also an IMOS sub-facility)
NRS	National Reference Stations; an IMOS sub-facility
NSW	New South Wales
NSW OEH	New South Wales Office of Environment and Heritage
NTP	New Technology Proving
NZODN	New Zealand Ocean Data Network
OBIS	Ocean Biogeographic Information System
ODP	IODE Ocean Development Program
OGC	Open Geospatial Consortium
OpenGTS	Open Global Telecommunication System project of JCOMM
PHP	PHP: Hypertext Preprocessor
PM	Project Management
PMEL	Pacific Marine Environmental Laboratory [NOAA]

PostgreSQL	See technical glossary
PRINCE2	PRojects IN Controlled Environments, generation 2
QA	Quality assurance
QC	Quality Control
QLD	Queensland
RabbitMQ	See technical glossary
RAN	Royal Australian Navy
RDC	Research Data Cloud
RESTful	See technical glossary
RLS	Reef Life Survey
RPS	Global professional services firm.
SA	South Australia
SARDI	South Australian Research and Development Institute
SISMER	French Research Institute for Exploitation of the Sea (IFremer) Scientific Information Systems
SOOP	Ship of Opportunity Program
SOOS	Southern Ocean Observing System
SOTS	Southern Ocean Time-Series mooring; also an IMOS sub-facility
SQS	Amazon Simple Queue Service
STAC	IMOS Science and Technology Advisory Committee
TAG	AODN Technical Advisory Group
TERN	Terrestrial Ecosystem Research Network infrastructure (NCRIS)
THREDDS	THematic Real-time Environmental Distributed Data Services
TileDB	See technical glossary
TS	Temperature-Salinity
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSW	University of NSW
UQ	University of QLD
URL	Uniform Resource Locator
US	United States of America
UTAS	Uinversity of Tasmanaia
UWA	University of WA
VIC	Victoria
WA	Western Australia
WAMSI	Western Australian Marine Science Institution
WCS	Web Coverage Service
WFS	Web Feature Service
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WMS	Web Map Service
WPS	Web Processing Service
XML	eXtensible Markup Language

Attachment E.   Documentation provided to the Review.

- IMOS National Science and Implementation Plan 2015-25
- A selection of IMOS Annual business plans, 2009 through to the present
- National Marine Science Plan 2015-2025
- A selection of 2015-2025 Node plans
- AODN implementation plans from 2016 to the present
- Various presentations/articles on AODN by members of the AODN team
- Examples of the AODN Newsletter
- (AODN) TAG Terms of Reference
- Examples of AODN Project Management documentation
- New Technology Proving project plan for "Ocean Data on Demand "
- Marine Research Data Cloud report "A Review of Biological Data Accessibility within the IMOS-AODN Portal", Jason Everitt (2019)

Attachment F.   List of stakeholder consultations

Table 5. Stakeholder list developed for the Review, ordered by category. I, M, S and E indicate an interview, meeting, survey or email, respectively.

	Contact	Stakeholder	Category	Interview	Survey	Comments
1.01	Michelle Heupel	IMOS Director	IMOS	I 1		
1.02	Indi Hodgson-Johnston	IMOS Deputy Director	IMOS	I 26		
1.03	Paul van Ruth	IMOS Science Officer	IMOS	I 34		
1.04	John Gunn	IMOS Board Chair	IMOS			Corresponded
1.05	Andreas Schiller	IMOS Board Member(s)	IMOS	I 28		
1.06	Nichole Brinsmead	IMOS Board Member(s)	IMOS			Corresponded
1.07	Toni Moate	NMSC Chair	IMOS	I 12		
1.08	Kim Picard	NMSC Deputy Chair	IMOS	I 12		
2.01	Sebastien Mancini	AODN Manager	AODN	I 2; Ms 2-6		
2.02	Jacqueline Hope	AODN staff	AODN	Ms 2, 6		
2.03	Guillaume Galibert	AODN staff	AODN	Ms 2, 3, 5		
2.04	Cameron Moloney	AODN staff	AODN	Ms 2, 4, 5		
2.05	Marty Hidas	AODN staff	AODN	M 3		
2.06	Natalia Atkins	AODN staff	AODN	M 3		
2.07	Craig Jones	AODN staff	AODN	M 4		
2.08	Leigh Gordon	AODN staff	AODN	M 4		
3.01	David Hughes	National Mooring Network	FACILITIES	I 30	S 8	
3.02	Craig Steinberg		FACILITIES			Retired
3.03	Rudy Kloser	Ships of Opportunity	FACILITIES			Retired
3.03	Haris Kunnath	Ships of Opportunity	FACILITIES		S 21	
3.04	Peter Oke	Argo	FACILITIES	I 5	S 3	
3.05	Elizabeth Shadwick	Deep water moorings	FACILITIES	I 4	S 6	
3.06	Dr Bernadette Sloyan	Deep water moorings	FACILITIES	I 4		

3.07	Dr Eric Schulz	Deep water moorings	FACILITIES	I 4	S 4	
3.08	Dr Tom Trull	Deep water moorings	FACILITIES			Semi-retired; did not contact
3.09	Prof. Charitha Pattiaratchi	Ocean gliders	FACILITIES	I 7		
3.10	Prof. Stefan Williams	AUV	FACILITIES	I 31b		
3.11	Rick Stuart-Smith	NRMN	FACILITIES	I 31a		
3.12	Dr Simone Cosoli	Ocean radar	FACILITIES	I 19	S 15	
3.13	Prof Rob Harcourt	Animal sensor network	FACILITIES			Corresponded
3.13	Clive McMahon	Acoustic tagging sub-facility	FACILITIES	I 35		
3.13	Fabrice Jaine	Animal tracking sub-facility	FACILITIES	I 35		
3.14	Scott Bainbridge	Wireless sensor network	FACILITIES		S 1	
3.15	Dr Edward King	Satellite remote sensing	FACILITIES	I 25	S 24	
3.16	David Antoine	Satellite remote sensing	FACILITIES	I 25	S 24	
3.17	Jodie Van De Kamp	Marine microbiome	FACILITIES	I 11		
3.18	Andrew Bissett		FACILITIES			No reply
3.19	Madeleine Cahill (AIMS)	OceanCurrent	FACILITIES	I 13	S 25	
3.50	Mun Woo from Glider facility	Members of IMOS facilities	FACILITIES		S 7	
3.51	Bec Cowley	Members of IMOS facilities	FACILITIES		S 10	
3.52	Pete Jansen	Members of IMOS facilities	FACILITIES			Promised
3.53	Jessica Benthuysen	Members of IMOS facilities	FACILITIES		S 17	
3.54	Claire Davies	Members of IMOS facilities	FACILITIES	I 8	S 2	
3.55	Simon Spagnol	Members of IMOS facilities	FACILITIES			No reply
3.56	John Akl	Members of IMOS facilities	FACILITIES			No reply
3.57	Ariell Friedman	Members of IMOS facilities	FACILITIES		S 34	
4.00	Justin Seymour	NSW	NODES		S 28	
4.01	Tim Ingleton	NSW	NODES		S 28	
4.02	Dr Nicole Jones	WA	NODES	I 15	S 14	
4.03	Ming Feng	WA	NODES	I 15		
4.04	David Antoine	WA	NODES	I 15		
4.05	Richard Brinkman	QLD	NODES	I 14	S 16	
4.06	Ana Redondo Rodriguez	SA	NODES	I 9		
4.07	Charlie Huveneers	SA	NODES	I 23		

4.08	Daniel Ierodiaconou	Victoria	NODES			No reply
4.09	Bea Pena-Molino	Bluewater and Climate	NODES	I 10	S 13	
4.10	Andrew Lenton	Bluewater and Climate	NODES	I 10		
4.11	Rob Johnson	Bluewater and Climate	NODES	I 10		
5.00	Tim Ingleton	NSW OEH	EXTERNAL DATA			Replied; covered with facility
5.01	Randall Lee	EPA VIC	EXTERNAL DATA			No reply
5.02	Peter Walsh	IMAS	EXTERNAL DATA	I 32	S 26	
5.03	Emma Flukes	IMAS	EXTERNAL DATA	I 32	S 26	
5.04	Barb Hayden	NZODN	EXTERNAL DATA			No reply
5.05	Kevin MacKay	NZODN	EXTERNAL DATA			No reply
5.06	Jochen Schmidt	NZODN	EXTERNAL DATA		S 27	
6.00	Tara Martin	CSIRO	ORGANISATIONS	I 17	S 12	
6.01	Andrew Carroll	Geoscience Australia	ORGANISATIONS			Scheduled to join
6.02	Kim Picard	Geoscience Australia	ORGANISATIONS	I 22		
6.03	Craig Steinberg	AIMS	ORGANISATIONS			Retired
6.04	Richard Brinkman	AIMS	ORGANISATIONS	I 14		
6.05	Mark Rehbein	AIMS	ORGANISATIONS			No reply
6.06	Diana Greenslade	Bureau of Meteorology	ORGANISATIONS	I 16		
6.07	Kate Roberts	Bureau of Meteorology	ORGANISATIONS			No reply
6.08	Johnathan Kool	AAD	ORGANISATIONS			No reply
6.09	Mark Doubell	SARDI	ORGANISATIONS			No reply
6.10	Ryan Lowe	UWA	ORGANISATIONS	I 36		
6.11	Luke Twomey	WAMSI	ORGANISATIONS			No reply
6.12	Andrew Walsh	RAN	ORGANISATIONS		S 22	
6.12	Marty Rutherford	RAN/GEOINT	ORGANISATIONS		E 2	Suppl. historical information
6.13	Dave Watts	OBIS Australia	ORGANISATIONS	I 21	S 8	
6.14	Scott Francis	Parks Australia	ORGANISATIONS	I 27	S 20	
7.00	Derrick Snowden	US IOOS	INTERNATIONAL	I 33		
7.01	Sylvie Pouliquen	Coriolis France	INTERNATIONAL			Declined
7.02	Michelle Fichaut	SISMER, IFREMER	INTERNATIONAL			Declined
7.03	Thierry Carval	SISMER, IFREMER	INTERNATIONAL			Declined

7.04	Peter Pissierssens	IOC/IODE	INTERNATIONAL		E 1	
7.05	Mary Wohlgemuth, Director	NODC/NCEI	INTERNATIONAL			Replied; Hernan the contact point
7.06	Ken Casey	NODC/NCEI	INTERNATIONAL			No reply
7.06	Hernan Garcia	NODC/NCEI	INTERNATIONAL			Completing survey
7.07	Toste Tanhua	Lead author FAIR paper?	INTERNATIONAL			Did not contact
7.08	Kevin O'Brien PMEL	ERDDAP expert	INTERNATIONAL	I 29		
7.09	Sergey Belov	IODE ODP	INTERNATIONAL			Did not contact
7.10	Adam Leadbetter	Marine Institute in Ireland	INTERNATIONAL	I 37		
7.11	Rob Thomas	Marine Institute in Ireland	INTERNATIONAL	I 37		
7.12	Louise Newman	SOOS	INTERNATIONAL		S 31	
7.13	Pip Bricher	SOOS	INTERNATIONAL		S 31	
7.14	Karen Stocks	Scripps	INTERNATIONAL			No reply
7.15	Peter Thijsse	Maris	INTERNATIONAL			No reply
7.16	Jeremy Tandy	IT Architect Met Office	INTERNATIONAL	M 4		
8.00	Rosie Hicks	Director ARDC	Other NCRIS			Declined
8.01	Sean Smith	Director NCI	Other NCRIS			Hand-balled
8.01	Ben Evans	Associate Director NCI	Other NCRIS			Replied - promised x 2
8.02	Andrew Gilbert	Director BPA	Other NCRIS	I 24		
8.03	Andre Zerger	Director ALA	Other NCRIS		S 29	
8.04	Miles Nicholls	Data Manager ALA	Other NCRIS			No reply
8.05	Lesley Wyborn	NCI/ARDC	Other NCRIS			Has replied; reminder, promises
8.06	Siddeswara Guru	TERN	Other NCRIS		S 27	
9.00	Vanessa Lucieer (UTAS)	User	Users at large			No reply
9.01	Mark Hemer (CSIRO)	User	Users at large	I 18	S 19	
9.02	Mark Baird (CSIRO)	User	Users at large	I 6		
9.03	Steve Buchan (RPS)	User	Users at large		E 3	
9.04	Claire Davies (CSIRO)	User	Users at large	I 8	S 2	
9.05	David Griffin (CSIRO)	User	Users at large	I 3	S 4	
9.06	Alistair Hobday (CSIRO)	User	Users at large			Promised
9.07	Patrick Hone (FRDC)	User	Users at large			No reply
9.08	Eduardo Klein Salas (AIMS & UTAS)	User	Users at large			No reply

9.09	Rachel Przeslawski (AMSA)	User	Users at large			No reply
9.10	Cedric Robillot (GBRF)	User	Users at large			No reply
9.11	Jason Everett (UQ)	User	Users at large	I 8	S 2	
9.12	Mark Underwood (CSIRO)	User	Users at large			Replied. Did not pursue
9.13	Ian Young (UniMelb)	User	Users at large			No reply
9.14	Moninya Roughan (UNSW)	User	Users at large	I 20	S 23	
9.15	Paul Hedge	User	Users at large			No reply
9.16	Nick Mortimer	User	Users at large			Promised
9.17	Amandine Schaeffer	User	Users at large		S 11	
9.18	Iain Suthers	User	Users at large		E 4	

Attachment G. Survey Form for Facilities

This is a forward-looking review examining the AODN program and processes to ensure the AODN facilitates efficient and optimised data access and delivery of derived products to Australia's marine science community now and into the future. The review needs to consider the current and future capability (i.e., skills, infrastructure, partnerships) of the AODN program.

AODN REMIT

1. Populating the AODN with publicly funded data and making this accessible to a broad national and international community, particularly data from IMOS-based research infrastructure,
2. Implementing FAIR (Findable, Accessible, Interoperable, Reusable) data principles,
3. Developing and maintaining tools to ingest, visualise and analyse data using project management methodologies (e.g., business analysis, project communication, functional specification development and framework design),
4. Encouraging and developing a culture of data sharing across the marine science community of Australia,
5. Developing and applying content and delivery-based standards for marine data and metadata to support Australia's science, education, environmental management and policy needs,
6. Maintaining robust and reliable infrastructure and professional data services,
7. Developing data management procedures and workflows that result in the improvement of data quality, its accessibility and re-usability,
8. Specifying, developing and deploying advanced e-services as part of a broader-based institutional Virtual Research Environment to facilitate individual and collaborative research.

TERMS OF REFERENCE: SYNOPSIS

Remit and scope

Task 1. Examination of the AODN remit

Strategy and planning

Task 2. Provide recommendations on improvements to current practices and how the program can be configured to meet current and future needs.
Task 3. Examination of current processes for business case development and project planning.

Capability and capacity

Task 4. Consideration of the capability, effectiveness, efficiency and agility of the current program.
Task 5. Assess if the AODN capability is adequate and appropriate.
Task 6. Examination of current IT systems and processes for maintenance and expansion of the existing AODN data infrastructure.

Impact

Task 7. Examination of data accessibility and channels of use and uptake.
Task 8. Stakeholder feedback of AODN ease of access, issues and delivery.

Benchmarking

Task 9. Comparison of infrastructure and performance to programs with similar remit.

QUESTIONS FOR FACILITY LEADERS

(1) REMIT, PLANNING AND PROCESS
Goal: *To provide effective planning and other business processes appropriate to the remit of AODN.*

KEY REVIEW QUESTION:
1(a) To what extent is the AODN using best practice in its strategic, implementation, and annual planning, and in its business development and practices?

Your response:

ADDITIONAL QUESTIONS:

1(b) To what extent has the AODN remit identified the right scope and targets to deliver the outcomes and impact sought, and that those challenges inherent in the remit are both sufficiently future orientated and ambitious, but also technically achievable?

Your response:

1(c) Does AODN have effective processes for scoping, planning, and costing new work, including business case development and approval, and project execution, assessment management?

Your response:

1(d) [OPTIONAL] Which of the following would you use to rate AODN's overall performance in terms of planning and processes?

Benchmark	Using and/or defining best practice for all aspects of planning, operations, and business development.
Strong	Using best practice for most aspects of planning, operations, and business development.
Favourable	Moving toward best practice for most aspects of planning, operations, and business development.
Tenable	Moving toward best practice for some aspects of planning, operations and business development – a sense of being continually a follower.
Weak	Few if any instances of best practice for planning, operations and business development.

(2) CAPABILITY AND CAPACITY

Goal: To provide fit-for-purpose IT systems and other capability to meet AODN objectives, and a capacity that is matched to current needs and scalable for future requirements.
KEY REVIEW QUESTION:

2(a) Is the AODN capability and capacity adequate and appropriate to fulfil and deliver the remit and objectives of AODN effectively, efficiently and flexibly, now and into the future?

Your response:

ADDITIONAL QUESTIONS:

2(b) Is the composition of skills, experience, expertise and agility within the current team fit-for-purpose and adequate?

Your response:

2(c) [OPTIONAL] Which of the following would you use to rate AODN's overall performance in terms of capability and capacity?

Benchmark	Conditions, including the operating environment, are optimally supporting the goals and objectives and benefits are being realised to a high extent.
Strong	Conditions are effective in supporting the goals and objectives of AODN and benefits are being realised.
Favourable	Enabling conditions are somewhat patchy but are starting to gain momentum.
Tenable	Aware of the issues and operating conditions impacting effectiveness and starting to address them.
Weak	Prevailing conditions do not promote success and little to no awareness of issues exists.

Your response:

(3) IMPACT
Goal: *To deliver efficient and optimised data services and derived products to Australia's marine science community.*[27]

KEY REVIEW QUESTION:
3(a) To what extent is the AODN being adopted as the preferred national manager of observations and source of ocean information, and making a difference nationally?

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[27] "Impact" here covers the quality of services provided for data ingestion as well as serving of data via the AODN Portal.

Your response:

ADDITIONAL QUESTIONS:

3(b) Are the existing arrangements with AODN and workflows appropriate and effective for your Facility? Can you see areas for improvement?

Your response:

3(c) To what extent are AODN data ingestion systems being recognized and adopted by stakeholders more broadly? Have barriers to uptake and adoption been overcome?

Your response:

3(d) More generally, to what extent is the AODN delivering a compelling national benefit through its data contribution services?

Your response:

3(e) Has the AODN developed robust practices to plan, monitor, evaluate and adjust activities in its data contribution services?

Your response:

3(f) To what extent has the AODN demonstrated the ability to form partnerships, relationships and otherwise catalyse activity to achieve impact?

Your response:

3(g) Which of the following would you use to rate AODN's overall performance in terms of impact of its services? Your response:

Benchmark	The AODN are, by design, being used or will be used to set the pace and direction of data and information provision and uptake nationally. The AODN is leading in its approach and is on track to achieve and exceed the IMOS goals.
Strong	The AODN are enabling strong data and information provision and uptake nationally and globally and is on track to meet the IMOS goals.
Favourable	The AODN are creating a favourable environment for data and information provision and uptake nationally and is on track to meet most of its goals.
Tenable	The AODN is partly delivering effective data services.
Weak	The AODN is generally not delivering effective data services.

Attachment H. Terms of Reference AODN TAG

1. Title

The name of the Committee is the Australian Ocean Data Network Technical Advisory Group. This group also forms the Marine Data Sub-Committee of the National Marine Science Committee.

2. Purpose

- Provide a forum for developing data management and data publishing standards for the Australian marine community.
- Provide technical advice to the Australian Ocean Data Network, to organisations wishing to publish marine data and data enabled platforms within the Australian Marine Data Landscape.
- Review new activities for data enabled platforms within the Australian Marine Data Landscape
- Provide advice and recommendations on the Australian Marine Data Landscape to the National Marine Science Committee (NMSC).

3. Membership

Membership shall be open to the following:

- A representative of each of the Commonwealth research agencies with an interest in marine data (for example the Australian Antarctic Division, the Australian Institute of Marine Science, the Bureau of Meteorology, CSIRO Marine and Atmospheric Research, Geoscience Australia, the Royal Australian Navy);
- A representative of each Commonwealth department with an interest in marine data (for example the Department of Agriculture, Water and the Environment);
- A representative of each State and Territory Government;
- Representatives of the private marine sector;
- Representatives of the University sector;
- The AODN Director, Data Services Team Leader and Information Infrastructure Team Leader;
- A representative of each initiative enabled by the National Collaborative Research Infrastructure Strategy (NCRIS) with an interest in marine data;
- A representative of the New-Zealand marine Geospatial working group;
- A representative of the Integrated Marine Observing System (IMOS).

Committee members shall have line management responsibilities for marine data management within their agencies.

Additions to the membership list shall be approved by committee co-chairs.

4. Functions

- To develop and advocate the use of appropriate standards for marine data management and publishing, develop local implementations of standards within member organisation.

- To act as a source of advice and assistance for any party wishing to publish marine data.
- To review and advise data enabled platforms developed as part of the Australian Marine Data Landscape.
- To represent the Australian marine community at national and international gatherings concerned with marine data.
- To review and make recommendations on the AODN Implementation Plan and subsequent progress.
- To form working groups to address specific issues arising from the AODN implementation Plan.
- To advise on the functionality required in the AODN Portal and the effectiveness of the AODN Portal.

5. Funding

The Committee is unfunded. The costs of any member participating in Committee activities shall be borne by the member's employer. Meetings shall be hosted by one of the participating bodies without charge.

6. Governance

6.1. Structure

The Committee shall have two co-chairs.

One of the co-chairs shall be the AODN Director.

The members of the Committee shall elect a second co-chair for a period of two years. Elections shall be held during a meeting of the Committee and only those members attending the meeting shall be eligible to vote. Election shall be by simple majority.

The responsibilities of the two co-chairs include:

- Maintaining a list of members of the Committee;
- Scheduling meetings and notifying committee members;
- Preparing an agenda for each meeting and ensuring that all necessary documents are attached to the agenda;
- Distributing the agenda and meeting documents one week prior to each meeting;
- Guiding the meeting according to the agenda and time available;
- Taking notes and preparing minutes of each meeting;
- Distributing the minutes after approval by the committee.
- Writing a report summarising activities before NMSC meetings.

6.2. Meetings

Meeting shall be held at least three times per year, to fit the business cycle of the AODN and preceding the NMSC meetings wherever possible. At least one meeting per year shall be face-to-face. Other meetings may be by electronic means. Where a Committee member is unable to attend a meeting, they may nominate an alternative to attend in their place. This nomination must be received by the two co-chairs before the meeting,

6.3.   Reporting

Meeting minutes and other reports will be sent to the National Marine Science Committee (NMSC).

6.4.   Working Groups

The Committee shall establish working groups to address specific issues as required. Working groups will have clearly defined deliverables and will normally have a limited lifetime.

- The Committee may invite anyone with suitable knowledge to participate in a working group but there must be at least one member of the Committee on each Working Group.
- The Committee shall establish terms of reference for each working group that is established.
- The Committee shall choose a Chair for each working group, selected from amongst Committee members.
- The Chair of each working group shall report to the Committee at each Committee meeting.
- Once established, a working group shall develop a plan for delivering the required outputs, including a timetable.
- The Committee may extend the lifetime of a working group if there is an identified need.

7. Amendments to the Terms of Reference

Amendments to these terms of reference shall be by unanimous agreement of existing members of the Committee and endorsement of the National Marine Science Committee.

8. Disbandment of the Committee

In order to disband the Committee, at least one month's written notice of a disbandment motion must be given to the members. Only those members attending the meeting where the motion is put may vote. A two thirds majority of the votes is required to pass the motion.

Attachment I. Analysis of Selected Projects

Animal Tracking Web Interface Project

The Animal Tracking Facility (ATF; formerly the Australian Animal Tagging And Monitoring System, AATAMS) was established as an animal acoustic tracking network which is now a sub-facility of the ATF. The existing system was failing, both from a technology perspective (increasingly difficult to maintain because of obsolete technology) and from a user perspective. The purpose of this project was to introduce a new architecture and rebuild the functionality based on new technology, mostly already adopted in AODN. The web-interface would be re-built and divided into separate components; an Application Program Interface (API) layer and a modern web interface. The existing database (which was a bespoke capability of AODN - see discussion in section 5.1.1 and Figure 4) would be retained. According to the plan "The new Animal Tracking web-interface will use new frameworks and modern architecture which will support the adding of new features post implementation".

The Review interviewed the ATF, AODN (multiple times) and the IMOS Director and concluded the project experienced multiple issues, from the point of proposal through planning and to the initiation of the project. There are differences of view on several aspects. The Review drew the following conclusions:

(i)   The acoustic animal tracking web interface and database are bespoke capabilities within IMOS/AODN (see section 5.1.1 and Figure 4). The reasoning behind that decision was beyond the scope of this Review but clearly such decisions do not aid scalability and efficiency, as per the terms of reference of this Review. The Reviewer is not satisfied from the evidence available that this bespoke development was justified.

(ii)   A proposal was presented by ATF/AODN to the Governing Board to undertake a major upgrade of the database and web interface; AODN provided advice and cost (effort) estimates for the proposal. The option recommended by the Facility/AODN (Option 4 of the proposal) was considered to be "overly ambitious at a cost of $0.5M over three years … [and asked the proponents] … to consider other options … $250K be reserved for this task".

(iii)   The ramifications from this decision were complex, in part because of the lack of specificity in the proposal, in part because of poor cost estimation by AODN (the two issues are related), but also because the decision was interpreted in different ways (lack of clarity). One party interpreted it as approval to proceed, but with AODN receiving reduced funding. Another that the project needed to reduce its scope. The decision appeared to say: develop a fifth option with a target budget of $250K, with final sign-off by the IMOS Director (similar to the two-stage approval process described in section 3.3.2). The Review has taken these learnings into the Findings. This situation was compounded by the fact that both AODN and IMOS were undergoing leadership transitions.

(iv)   The actual intent of the decision remained unclear to the Reviewer. Did the Governing Board (presumably on the advice of the then IMOS Director) conclude that there was gold-plating in the costings, and so the AODN should find savings in the costings with the rest to be borne by reduced scope? Were the objectives too ambitious, noting that the proposal to the Board had already deleted plans for new features (on STAC's advice?). It appeared that AODN and ATF heard different messages.

(v)   This Reviewer struggled to understand the budget but accepts that detailed costings have been developed. The Table below summarises the Reviewer's understanding. Note that the budget is given in dollars, not in FTE – the practice of using FTE as a currency should be discontinued. While the Gantt chart that accompanied the proposal indicated a project lifetime of 15-18 months, the inclusion of bids for enhanced core funding (maintenance) suggested it was costed over three years. The reduced approved funding led to proportionate reductions in project build and maintenance funding. To deliver functionality required by ATF $337.5K of AODN resources were shifted toward ATF (the maintenance shortfall for what was otherwise a like-for-like replacement appeared to stem from the fact that this was previously not taken into account). Note that planning costs (which were considerable for all stakeholders) were not covered by the capital injection.

Table 6. Budget for the ATF web-interface project. Part of the existing core resource would be involved with the project build. Most of the additional funding was earmarked for s/w development. AODN shortfall are the amounts AODN is diverting from its regular budget toward the ATF web-service development and maintenance. The ATF shortfall was for enhancement activities.

Year	Core existing	Proposed new	Approved new	Nominal Shortfall	AODN shortfall	ATF shortfall
1	$125K	$250K	$125K	$125K	$225	$100K
2	$125K	$125K	$62.5K	$62.5K	$56.3K	$100K
3	$125K	$125K	$62.5K	$62.5K	$56.3K	$100K
Total	$475K	$500K	$250K	$250K	$337.5	$300K

(vi)   The Reviewer has been unable to determine whether the shifted resourcing toward ATF was intended. It appeared to the Review that maintenance costs that were formerly implicitly budgeted through the Facility (for the web interface, not the database) were now to be covered by AODN and should not have been bundled in with the proposal. The project build shortfall is nearly two times the amount approved for the project build, with another $100K needed for the enhancements. These are large prices to pay for the failed process.

(vii) It is quite clear the efficiency of the project planning was poor. Being guinea pigs for the PM roll out must have been difficult for ATF. The time in planning exceeded the execute time. Some of the failings have been discussed in section 3.3.1 (too heavy; confusion around the business case because of uncertainty surrounding the decision; too risk averse; too much process, e.g., around communication plans and training. However, this Reviewer concluded that the final Implementation Plan was fit for purpose and broadly in keeping with the level of specificity one would expect for such a project.

(viii) The renegotiated project was a lengthy and unpleasant process for all parties. The sub-facility was subjected to a near-full PM Prince 2 approach, complete with an after-the-fact business case and ancillary documentation. As requirements were fleshed out in more detail, the cost grew and led to inevitable AODN pushback. The negotiation appeared to lack boundaries. The AODN attempted to properly document the functional requirements and provide detailed costing against these requirements, but the cost ballooned beyond the guidance provided by the Governing Board.

(ix)   The one positive is that ATF and AODN have worked well together for project execution which appeared to be on schedule and on budget.

National Reef Monitoring Network

The NRMN project was originally pitched as a comprehensive Facility for managing Reef Life Survey (RLS) data, including surveys in Marine Parks. The proposal submitted for Governing Board approval was narrowed to focus IMOS effort on redevelopment and management of a single database for Reef Life Survey (RLS) and Australian Temperate Reef Collaboration (ATRC) program data and working with collaborating institutions and RLS divers on an ongoing basis to ingest and quality control new shallow reef survey data.

The Review has not seen the project proposal (business case) that was taken to the Governing Board, just the advice provided by the then IMOS Director to the Board. The so-called business case developed jointly by AODN-IMAS is not useful for understanding the approval. Once more the build is proposed as a bespoke development (different ingestion pathway; separate database), not integrated with the Pipeline ingestion system used elsewhere. The reasons were not clear, other than the fact they were different types and forms of input data (spreadsheets, etc.) cf. other data streams. It is the Reviewer's understanding from an interview with the NRMN that the proponents thought they were proposing a self-build and were unaware the systems would be developed and maintained by AODN, which would likely increase the cost. The original proposal did not contain functional specifications, just general statements and a budget (for the IMOS funding; Table 7). The documentation available did not list co-contributions.

Table 7. IMOS budget for NRMN.

Expense	Type	Operator	2018-19	2019-20	2020-12	2021-22	Total
Data Officer(s)	Salary	IMAS	40,890	99,590	101,590	103,610	276,540
Miscellany	Operating	IMAS	5,000	10,000	11,000	12,588	38,588
Database develop/maintenance	Salary	AODN	25,330	165,000	62,093	62,200	314,623
Total			**71,220**	**274,590**	**174,683**	**178,398**	**698,891**

The Reviewer found:

- As with the ATF Project, the decision of the Governing Board seemed more at the conceptual level cf. approving a project proposal. That is, it was agreed a new sub-facility would be created for NRMN, and that a budget of around $700K would be provided by IMOS to make the sub-facility functional. Details of the functionality would be negotiated between the operators of the sub-facility and AODN, presumably with sign off of this more detailed business case delegated to the IMOS Director. Some clarity was lacking.
- Assuming this interpretation was correct, the next step should have been to develop a costed project plan within these general constraints, including the decision that it would be built within AODN rather than as a self-build. The development of a PM business case was not needed though in practice the document doubled as the project plan (and referred to as such below).
- Part 1 to 4 of the plan should have, but likely did not match the proposal presented to the Governing Board. The Reviewer concluded the project plan Scope was far too detailed for this initial step (even if the detail was needed for costing) and almost certainly would have led to considerable delay getting approval. The six items under "In scope" needed just enough description to explain what was required, not a long list of tasks. This Reviewer does

not understand the purpose of items listed as under consideration or out of scope; by definition, if they are not in scope, they do not need to be considered in the project plan, and certainly not at the task level. These long lists may mitigate the risk of misunderstandings and/or false expectations, particularly if the partners in the project do not understand each other's terminology, but they should not clutter up the project plan. They should simply be recorded/minuted as part of the planning process. The Communications section detail is likewise overdone for a project of this size. The Resource part belongs in an Implementation Plan. The Cost section, on the other hand, is probably underdone. It must include a clear budget within the document, much as above, but also detailing critical in-kind external resources needed for the project.

- In summary, the NRMN project, like the ATF project, was set in motion without sufficient clarity around functional expectations and the time frame for implementation. It too suffered from over-zealous PM and a client who was unprepared for the detailed specifications that would be required before agreeing an Implementation Plan. The transition from Board decision to detailed planning exacerbated issues in plan negotiation (there really should not be a negotiation of scope).

Long Time-Series Project

The National Mooring Network - Long Time Series Products (LTSP) project is included as a case study because it is an area that is important strategically for IMOS/AODN – developing value-added products.

The objective of the project was to develop a set of new products combining common variables across NMN instruments to produce a form/database that was better structured and in a more accessible format. The project responded directly to user need and feedback and was intended to demonstrably improve usability and broaden utility.

The Reviewer has not conducted a deep-dive into the project but does draw some general conclusions:

- The Reviewer was provided with six separate "business cases" and three separate Implementations Plans for the project:
    - 00-LTSP_Bcase_2019-2020_Products.pdf
    - 01-LTSP_Bcase Non-Velocity AGGREGATED.pdf
    - 02-LTSP_Bcase Non-Velocity HOURLY.pdf
    - 03-LTSP_Bcase Non-Velocity GRIDDED.pdf
    - 04-LTSP_Bcase Velocity AGGREGATED.pdf
    - 05-LTSP_Bcase Velocity HOURLY.pdf
    - 02-LTSP_IP Non-Velocity HOURLY.docx
    - 01-LTSP_IP Non-Velocity AGGREGATED.docx
    - 05-LTSP_IP Velocity HOURLY.docx

    One respondent was unable to understand the approach to business case(s), despite coming from an organisation that is experienced in PM; others lamented the excessive process and documentation. The Reviewer was unable to determine what drove this approach but

understood the motivation for each product. It was an important project, but this level and form of documentation seemed unwarranted – PM is after all designed to manage several sub-projects/work packages as a single project. It may have originated from a desire to have separate detail on scope: "An individual Business Case will be detailed and agreed for each product prior to development, that will specify the intended confines of the product within the Scope section". Once more, it was in the early days of PM.

- The "business cases" are once more not really business cases, but a form of project plan. The level of detail is more measured and seemingly better sized for the project (the budget was around $125K). At this level it should not have been necessary to break out separate plans, indeed the opposite is probably true.

- The Reviewer understands the project is completed but was unable to find the products of this work on the Portal.

- The project plan makes no reference to a Benefits Realisation step: a post release appraisal of whether the benefits targeted in the Outcomes have been realised. For user driven projects such as this such a step would appear critical.

Attachment J. Consolidated Findings

1. Background
2. Remit, scope and structure
   2.1. Remit and scope

Finding 1. IMOS, in consultation with partners of the 'national' AODN, must clarify the distinction between the IMOS capability (and program) known as AODN (and the subject of this review), and the 'national' AODN for which IMOS was a leading contributor, but not the sole owner. This clarification should include consideration of objectives and governance.

Finding 2. The scope and remit of the IMOS AODN need to be defined and approved by the IMOS Governing Board so that the responsibilities and accountability of the IMOS AODN are clear and transparent to IMOS and external stakeholders.

Finding 3. Additional clarification was needed concerning AODN's intergovernmental role and the extent to which AODN services should be driven by international requirements.

Finding 4. The AODN remit and objectives should identify scalability, efficiency and flexibility as important attributes of AODN functionality and capability in order for it to effectively support and deliver new data and products streams.

   2.2. Organisational structure

Finding 5. The Review concludes that added clarity was need around the organisational and strategic links between AODN, facilities, Nodes and the NTP projects.

Finding 6. The Terms of Reference of the Technical Advisory Group need to be reconsidered by IMOS in the light of other Findings of this Report. The references to AODN in the Terms of Reference need added clarity as does any formal relationship with IMOS.

Finding 7. The organisational arrangements for AODN within IMOS and nationally need to be clarified, including a definition of facilities and added clarity regarding the role of the STAC with respect to data management technology.

3. Strategy, planning and process.
   3.1. Strategic planning

Finding 8. AODN should develop a strategic plan, probably with a 3-5 year horizon, consistent with and following IMOS Strategy and developed alongside the IMOS 5-year plans. AODN clients should be engaged in the development of this Plan.

Finding 9. The IMOS/AODN Policy settings and/or strategy need to be adjusted to ensure all AODN-held data have the best opportunity for impact, including through value-added products. Added clarity was needed around the strategic alignment of New Technology Proving projects and AODN, to guide planning for engagement.

   3.2. Annual business planning

Finding 10. The planning cycle for AODN should be revised, with strategy guiding prioritisation, and far greater transparency, and engagement earlier in the cycle, prior to the annual planning meeting. Plans should include indicative schedules for the out-years. The Annual Planning meeting should be used for finalisation and buy-in.

3.3. Projects and Project Management

Finding 11. The Review found that adoption of PRINCE2 by AODN alone led to several unintended consequences. PM should be endorsed by IMOS for use by AODN and ensure Facilities and the IMOS Office are fully briefed and familiar with the method. While it would be preferable for the PM methodology to be adopted throughout IMOS, including for decisions of the Governing Board, the fallback is to introduce processes that ensure decisions and resource allocation are consistent with the requirements of PM planning and implementation.

Finding 12. The Review found that project management methodologies adopted by the AODN (Scrum and PRINCE2) represent best practice and should be retained and strengthened for the future. However, variations to normal PM practice inevitably led to some frustration for both the sponsors and the clients.

Finding 13. The IMOS Office should consider a two-step decision making process for proposals that were heavy in IT and involve AODN, with the first step seeking approval for the high-level plan and intended outcomes, and the second for endorsement at a detailed level. The business case should be informed by adequate product description/ functional specification and rigorous costing. The pipeline of work for AODN should be tracked and managed with the IMOS Office to avoid overload and ensure essential core activities were sustained at the same time resources were brought to individual projects.

Finding 14. The AODN should be encouraged to broaden the base of investment in its activities, seeking co-investment and external contributions as appropriate. Pricing and cost recovery guidance should be developed to ensure projects deliver benefit to IMOS/AODN that was commensurate with investment by AODN.

4. AODN Capability and capacity
4.1. AODN Team

Finding 15. The Review could not find any persuasive evidence that AODN was either over- or under-resourced with respect to the objectives of IMOS but does conclude it was under-resourced for the grander national objectives. The IMOS investment in data management is comparable to or less than international counterparts. Weaknesses in planning and priority setting have likely contributed to a perception in AODN and IMOS generally that AODN was under resource pressure.

Finding 16. The appropriation of resources to AODN needs better definition and increased clarity and should be broken down into i) core, ii) internal project, iii) external project, and, if appropriate, iv) external contributions to core activities. Contingency should be built in for urgent maintenance issues.

Finding 17. The surveys and interviews revealed significant good will and respect for AODN, generally with the caveat that they have a very difficult task in front of them. Some were glowing in their praise for what AODN does, particularly around the ability to manage IMOS data. On the output side, issues with capacity and expertise (not enough science expertise in certain areas) were highlighted.

Finding 18. AODN should undertake a capability assessment with the assistance of a facilitator experienced in capability planning in IT technical organisations with a view to developing a capability plan. This assessment should consider staff development activities and career opportunities for AODN staff, irrespective of contracting arrangements.

Finding 19. The short-term contracting arrangements for AODN personnel was at odds with AODN's long-term mission to provide reliable curation and archiving of IMOS and other data, and inevitably leads to higher turnover of staff and higher recruitment costs than would otherwise be the case. The Review was informed of several instances where loss of staff had a material effect on efficiency and effectiveness. IMOS should investigate more suitable arrangements.

Finding 20. IMOS and AODN should test the pros and cons of out-sourcing in place of recruitment for future project builds.

4.2. AODN Infrastructure

Finding 21. The AODN has delivered a diversity of data in self-documenting architecture-independent open formats with widely used metadata standards and this was a momentous achievement in terms of architecture and infrastructure.

Finding 22. IMOS (and IMOS partners) should provide policy for data ingestion, including (i) the standards adopted for interface; (ii) the preference for QC to reside with the provider; (iii) conditions to be satisfied for data sources to become IMOS-approved and supported data flows; and (iv) the evolution toward a national role (the alternative pathways 3 and 4).

Finding 23. The Review identified several potential avenues to improve the architecture of the ingestion system, including consideration of recent changes to the OGC standards and the potential of systems available through the cloud (AWS).

Finding 24. The Review highlighted the need to consider strategy around a broader play by IMOS and AODN nationally, consistent with Finding 1 and Finding 2, and the likely need to lower the barrier of entry for national data flow.

Finding 25. The Review concluded that bespoke processing, storage and loading solutions should be the option of last resort. Where it was determined that a solution was not possible within the AODN architecture, consideration should be given to developing solutions in the cloud to lessen legacy costs; using skills and expertise of partners to develop prototype pipelines for AODN; setting sunset timelines to ensure bespoke activities received timely review and resetting.

Finding 26. The AODN should seek greater exposure and understanding of its different catalogues to inform users of the breadth and depth of data accessible and downloadable (perhaps indirectly) from the main Portal.

Finding 27. AODN should evaluate options for its Geonetwork as part of its review of AODN architecture. Full consideration should be given to cloud options that may be more cost-effective than AODN-built solutions.

Finding 28. AODN should research next generation search capabilities as part of its review of architecture and infrastructure. These capabilities may coexist with existing Portal capabilities or, eventually, provide a replacement.

Finding 29. AODN should, as a matter of urgency, engage an external IT architect to undertake a detailed assessment of its architecture. Major infrastructure decisions should be delayed until this was done.

Finding 30. AODN must find a more effective solution for querying and subsetting large datasets. The Review supported the plan to investigate cloud optimised gridded data services for its NetCDF data.

Finding 31. The Review supported the AODN use of commercially provided web services and noted they provided security and reliability for the AODN production system. The Review encouraged AODN to examine avenues for more effective exploitation of AWS offerings and to be open to greater use of proprietary systems (cf. self-builds) in the future.

Finding 32. There were opportunities to improve AODN handling of large (mostly gridded) NetCDF datasets. Given IMOS and AODN were seeking improved forms to improve usability (analysis-ready), there should be a specific call under the New Technology Proving program to develop a prototype for IMOS/AODN.

Finding 33. The arrangements around sharing the AODN stack need some added formality, noting that having one or two partial mirrors and/or alternative technical development sites could be mutually beneficial.

5. Data Services
   5.1. Data Ingestion and Curation

Finding 34. The Review found IMOS Workflows to be well-documented and provided surety around responsibilities through the lifetime of data from instruments into the AODN. The attention to detail was admirable and should withstand changes in technical aspects and in personnel.

Finding 35. AODN should reduce ad hoc incremental change and improvements to the dataset-specific pipeline handlers, Matlab Toolbox, and other technical elements of the workflow in favour of a planned and orderly review and update cycle.

Finding 36. Develop guidelines and policy for the IMOS data ingestion process.

Finding 37. Legacy datasets. IMOS and AODN should develop a position paper on legacy datasets (observations related to Facilities but collected before IMOS came into existence), noting that users might expect that all legacy data could be discoverable, accessible and downloadable through AODN.

Finding 38. Data publication. IMOS and AODN should develop guidance on data publication, data republication, and formal (documented and/or peer-reviewed) publication so that attributions and responsibilities were clear.

Finding 39. Documentation and versioning. The policy around publishing and handling multiple versions of the same data stream should be reviewed. This review should also consider scientific and technical guidance around the quality of the data and how to use available data.

   5.2. User Data Services - Impact and Responsiveness

Finding 40. Current IMOS and AODN strategy was not sufficiently user-driven and both must be updated to reflect its importance.

Finding 41. IMOS and AODN needed a form of user registration that would allow intelligence to be gathered on users and usage to inform future IMOS/AODN strategy.

Finding 42.   IMOS/AODN needed a dedicated channel (a User Desk) for soliciting user and client feedback and gathering intelligence on user demographics and IMOS data and product usage and future needs. It should be separate from AODN.

Finding 43.   AODN needed to enhance its skills and competencies in user/client relationship management to ensure all elements of their work could benefit from feedback, as AODN changed from a technical-driven to a user-driven program.

Finding 44.   AODN/IMOS to consider an annual or biennial user forum or similar mechanism to garner advice and input from Nodes, Facilities and other user groups. This should be convened mid-way through the planning cycle and should be user-oriented, not a technical display.

Finding 45.   The Review found that the lack of an active user uptake program meant that AODN and IMOS were being forced to take on some of that responsibility. IMOS should consider creating a modest user uptake program to foster the development of innovation and user applications.

Finding 46.   The Review found that a national strategy for agreeing standards for managing marine biological data, and for providing an effective (biological) data service was needed. The AODN/AODN TAG were well placed to lead such work from a technical perspective, but it was deemed essential to engage the marine biological community more broadly, including data providers and data users.

Finding 47.   The demand for changes and improvements in the AODN Portal was constant and enduring, and far outreached the ability of AODN to service those requirements. Changes to the Portal should be strategic and systematic; user community driven; feasible and viable within the limitations of architecture and IT infrastructure; and demonstrably impactful.

Finding 48.   The Review concluded the AODN Portal was at, or close to its end of life, with growing technical debt and a growing gap between where AODN should be and where it was now. A major refurbishment without substantial change in the architecture would likely not be cost effective or a viable longer-term solution.

Finding 49.   The current Portal should be frozen during the 2021-22 fiscal year and a plan for its replacement developed. There should be less self-build and more off-the-shelf/cloud services incorporated in its replacement. Its design should be user driven.

Finding 50.   The AODN Portal does not have the capability to manipulate or visualise data to meet a major demand from users for value-added products. IMOS needed to develop a specific strategy to meet this demand. AODN can contribute through co-design and co-development, as appropriate, but should make its focus the provision of effective data services to underpin this development. The strategy should focus on facilitation rather than a new set of facilities within IMOS.

Finding 51.   The AODN should continue to promote and contribute to a national interoperable network of marine and coastal data services with the AODN Portal providing a window to national data holdings. The AODN should also seek further opportunities to ingest, curate and publish publicly funded ocean and coastal observations more generally.

6.   Benchmarking

Finding 52.   AODN was rated favourable or better across most of the areas assessed by the Review. In the key area of data ingestion, the review found AODN to be strong, but for data services,

however, they rated less favourably. AODN people and infrastructure compared well against their papers, but for architecture they are facing significant challenges.

7. Synthesis and Recommendations
   7.1. Remit, scope and structure

   Recommendation 1   IMOS should provide added clarity around national provisions for ocean data management, in consultation with the NMSC, and adjust terms of reference, organisational arrangements and scope accordingly. A clear statement on the remit of AODN should be agreed.

   7.2. Strategy and planning

   Recommendation 2   The AODN should develop a strategic plan, reflecting the high-level strategy of the IMOS Plan, but also identifying aims and priorities to guide AODN plans. Stakeholders should be engaged in this process. The Annual Business Planning cycle should be restructured to allow greater external engagement and increased transparency around priorities.

   7.3. AODN business processes.

   Recommendation 3   IMOS should adopt Project Management methodologies to support project planning and execution of IT projects, harmonised with governing body decision making processes as appropriate. Project Management implementation should be right-sized for the size and complexity of projects and AODN should reset its processes accordingly.

   7.4. Human resources (capability, capacity)

   Recommendation 4   The review does not provide any recommendation for a change in base funding but does recommend adjustments to process so there is a clear line of sight for (a) base funded operations and maintenance (core), (b) base project capacity, and (c) fixed-term project funding.

   Recommendation 5   AODN should put in place capability planning processes, including options for out-sourcing when special needs arise. IMOS should explore options for more secure staffing arrangements consistent with the IMOS long-term strategy for AODN, to improve position competitiveness and to mitigate high staff turn-over rates.

   7.5. Architecture

   Recommendation 6   IMOS and AODN should reset policy and guidance for existing and potential data providers so that (a) required data and metadata standards were clear, (b) differentiated responsibilities and accountabilities were clear, and (c) integration into the AODN architecture was strongly preferred.

Recommendation 7 AODN should undertake a review and reset of its architecture as a matter of urgency, with scalability and efficiency included in the criteria, and an overall aim of greater flexibility to introduce new technologies. The resetting should include greater consideration of cloud solutions where appropriate.

7.6. IT infrastructure

Recommendation 8 AODN should assign high-priority to the need to find efficient and effective IT solutions for handling large datasets including querying and subsetting capabilities.

7.7. Data ingestion

Recommendation 9 Policy and guidance should be developed for the observation-AODN interface to make clear the differentiated responsibilities for quality assurance and quality control, the high standards on metadata and data, and the enduring responsibilities of data curation and publication that were borne by AODN.

7.8. Data and product delivery services

Recommendation 10 IMOS, with input from AODN, should review and update strategy to ensure greater focus on users and usability with identified actions to achieve such change.

Recommendation 11 AODN and IMOS should enhance capabilities and functionality for users including consideration of i) user registration, (ii) the creation of a User Desk, (iii) enhanced capability and capacity for user relationship management, (iv) a dedicated user forum, and (v) a system of user uptake grants.

Recommendation 12 IMOS and AODN, with its partners, should develop and agree a strategy specifically for (a) management and servicing of biological and ecosystem data, and (b) for developing value-added data and data products.

Recommendation 13 The AODN Portal, in both its national and IMOS manifestations should be replaced, to take advantage of new technology and to better position it to respond to future user needs.