AUV Review Continuation

March 2021

1. Introduction

1.1 Aims of Review Continuation

The aim of this Review Continuation is to assess the end-user demand for IMOS-funded autonomous underwater vehicle (AUV) deployments (i.e., the need for imagery collection) and the end-user value of IMOS increasing investment in image processing for the purposes of marine management based on suggestions in the External Review undertaken by Peter Doherty in 2020-21. This Review Continuation addresses several recommendations in the External Review and subsequent discussions with the IMOS Governing Board. Key recommendations examined include:

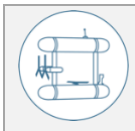
- R2. IMOS office engage marine management agencies in Victoria, NSW, and the Australian Government in 2021 to establish their demand for observations provided by the AUV Facility
- R5. IMOS note that AUVs compete with several other remote observing technologies, including light inspection class ROVs, offering more cost-effective benthic imaging in depths under 50 m
- R6. IMOS note that the least contested niche space for AUV observations is between 50 and 200 m
- R7. IMOS consider options to expedite automated classification of benthic imagery

Per Recommendation 2 of the External Review, this Review Continuation focused on the marine management agencies of various State and Commonwealth jurisdictions. A decision framework approach was applied to determine need and applicability of elements of the IMOS program.

Assessment of marine management need was conducted via interviews and desktop analyses across the three main components of the Facility: AUV Vehicle Operations, Benthic Imagery, and Image Annotations. Interviews were conducted with managers of state and Commonwealth marine parks and reserves. Where interviews were not conducted, the External Review was used to assume responses.

1.2 Structure

This Review Continuation is structured around the three components of the Facility:



AUV Vehicle Operations

This refers to the activities involved in collecting benthic imagery. Includes deployment, vessels, survey area selection, and logistics.

Benthic Imagery

This refers to the images of the benthic environment that the AUV collects. Images are currently uploaded into the IMOS Australian Ocean Data Network (AODN) AUV Image Database. These images are a raw output of the vehicle, prior to researcher analysis.

Image Annotations

This refers to the annotations and analysis of the benthic imagery and is the ultimate 'data' emerging from the Facility. These annotations of the benthic cover and substrate composition help interpret change, diversity, and other aspects of the benthic environment. IMOS supports the Understanding Marine Imagery (UMI) sub-Facility for management, exploring and annotating images from the Facility.

Via the funding of the UMI sub-Facility, it is intended that an open online annotation repository be created which will be discoverable and accessible through the AODN.

2. The Need for AUV Vehicle Operations

2.1 Context and method

Further information was sought to define end-user demand for vehicle deployments (i.e., the need for imagery collection) based on Recommendation 2 from the External Review. The overarching conclusion was that Parks Australia views itself as 'needing' IMOS AUV capability to achieve its benthic monitoring objectives. States indicated they would likely only 'need', or request, IMOS AUV capability in deeper marine park areas such as the Capes region of Western Australia and Kangaroo Island in South Australia or request the Facility for *ad hoc* purposes such as particular research questions (noting this is outside the objective of the Facility).

2.2 Need for benthic imagery collection

Most jurisdictions collect benthic imagery for management of their marine environments. [1] Images are needed for monitoring and specific research purposes, within marine protected areas (e.g., Australian Marine Parks and the Great Barrier Reef) or in areas of environmental significance (e.g., urchin barrens in Tasmania). The External Review noted that Tasmania, Victoria, and Queensland use benthic imagery for either management or research purposes. While not yet implemented, the *Northern Territory Marine Science End User Knowledge Needs Analysis* (NTSEUNA) identifies benthic environments as a scientific 'need' that should be included in future management processes.[2]

The need for benthic imagery is predominantly focused on monitoring of marine protected areas, and these requirements are built, or are being built, into various State and Commonwealth management frameworks. Some jurisdictions are undergoing change in management structures that could provide additional clarity in monitoring need in the future. Prioritisation exercises of Parks Australia are likely to include the need for benthic imagery for monitoring purposes, however this report will not be available until the end of 2021. While jurisdictions have verbally indicated their need for benthic monitoring, the management frameworks requiring or articulating such a need are not yet explicit in this need.

In the context of marine management, State needs for benthic imagery mostly exist in areas <50m in depth since almost all State marine protected areas are in this depth range, and other areas of significance such as urchin barrens are also in shallow water. The Commonwealth, however, has a need for benthic imagery from shallow reefs to deep ocean abysses, with over 80% of Australian Marine Parks (AMPs) in water >500m. Further, the Great Barrier Reef World Heritage Area has an average depth of 35m, with some of the outer reef being as deep as 2000m.

Conclusion: although some jurisdictions are currently designing and developing monitoring and management frameworks, most indicate some level of benthic imagery need for either monitoring or research purposes. The depths of the areas requiring monitoring vary greatly between the States and the Commonwealth, however States typically require observing in <50m depth. The External Review indicated most States already had existing benthic monitoring capability in this depth range. The main stakeholders in the proposed niche of 50-200m are Commonwealth agencies (Parks Australia and potentially the Great Barrier Reef Marine Park Authority).

[1] Interview responses were with WA, SA, New South Wales and Parks Australia. Due to various reasons, other jurisdictional analyses (Tasmania, Victoria, Queensland, and NT) are implied from the previous Review and other information.

[2] Barnett, R, *Northern Territory Marine Science End User Knowledge Needs Analysis* (2018), 108.

2.3 Need for IMOS AUV capability for benthic monitoring

Most jurisdictions indicated some level of need for an AUV capability for marine monitoring purposes. Reasons for this include the need for a vehicle for surveys in >30m, and the need for the quality of images that AUVs can provide when compared to other vehicle imagery.

Parks Australia does not own or operate its own AUV capability and has been one of the primary users of the IMOS Facility to establish baselines and monitoring in AMPs. Tasmania has also been a major user of the Facility, predominantly for University of Tasmania research into urchin barrens and the related loss of kelp forests on the East Coast as well as the development of AUV image collection and analysis methodologies. With some exceptions, these deployments mostly fall outside Tasmania's small network of marine protected areas.

Other jurisdictions indicated occasional use of the IMOS AUV Facility, with this response being reflected in the AUV deployment data from the AODN. Of these jurisdictions, Western Australia and South Australia indicated that their use of the AUV was mostly related to joint Parks Australia/State deployments, or one-off deployments in areas of scientific interest.

Where the IMOS AUV capability had been used by these other jurisdictions, support for deployment was mostly under the auspices of a National Environmental Science Program (NESP) Marine Biodiversity Hub project or one-off funding. For example, IMOS AUV deployments in the Ningaloo World Heritage Area, which spanned across State/Commonwealth lines for the benefit of AIMS and CSIRO research and monitoring, were facilitated by NESP funding.

It was apparent during interviews that the model of accessing the Facility (see notes on the Integrated Benthic Monitoring Program Group below) was perhaps a barrier to uptake and use by some jurisdictions. However, in noting the emerging capacity of jurisdictions, this may be a side-issue to most.

2.4 Use of own capability

As highlighted in the External Review, there are numerous other observing technologies that offer more cost-effective benthic imaging, particularly in depths under 50m.[3] In discussing capability with the marine managers of four jurisdictions, it was clear that there is an abundance of shallow water capability for the collection of benthic imagery.

Three jurisdictions noted the use of divers for surveys, which are not discussed in depth in either of the Reviews. It was noted by some that the risks to divers were becoming more worrisome and that capabilities such as ROVs and towed videos were intended to eventually replace the need for divers in some circumstances. Further, remote sensing was also mentioned as an emerging benthic monitoring technique in particularly shallow waters (see 3.3 *Emerging technologies and issues* below).

Most State jurisdictions have access to ROVs and towed video technology. In two cases these methods were in early stages of use and staff were still learning how to maximise their capability. Respondents said that challenges existed in deeper areas when using ROV and towed video capabilities. As mentioned above, the quality of AUV images in these deeper areas - when compared to these other capabilities - was considered a benefit of AUV deployments for marine management.

It is likely that Victoria has some capability to collect benthic imagery via collaboration with universities such as Deakin. This is evident through the Victorian Marine Mapping projects highlighted in the External Review.[4] The capabilities mentioned in these projects include towed video with downward-facing cameras, divers, and unmanned aerial vehicles for aspects of monitoring.

[3] Doherty, P, Independent External Review of the Integrated Marine Observing System (IMOS) Autonomous Underwater Vehicle (AUV) Facility (2021) Recommendation 5.

[4] Doherty, P (2021) 28; see also: https://www.marinemapping.org/pv-projects.

Capabilities within the Great Barrier Reef World Heritage Area are covered in detail in the External Review.[5] It is noted that through partnerships with the Australian Institute for Marine Science (AIMS), QUT, CSIRO, that AUV capability exists for monitoring of the marine park.[6]

This Review did not establish whether Tasmania and the Northern Territory have their own capabilities such as ROVs and towed video. With the proliferation of affordable and easily deployable vehicles that can access shallow coastal waters, however, these States will likely have the ability to access vehicles to collect benthic imagery for their marine management needs.

The vessels used to deploy benthic observing technology vary greatly around the country. New South Wales, South Australia, and Western Australia all have small vessels capable of deploying ROVs and towed videos. The South Australian RV *Ngerin* is also being fitted with a winch and cable for a towed video system. Queensland also has capability in the form of AIMS vessels, smaller research and compliance vessels, and increasing access to commercial tourist vessels. These small vessels are likely capable of deploying the Nimbus AUV, but could not deploy the Sirius.

The above discussion highlights the uptake and use of smaller and more affordable underwater image-collecting capabilities such as ROVs and towed videos by State jurisdictions. What is emerging is the need for an AUV-like capability in particular areas of deeper water, where States have a need to monitor these areas. This conclusion aligns with Recommendation 6 of the External Review that the niche space for AUV observations is somewhere between 50 and 200m where the smaller and more agile technologies currently do not have the ability to gather quality benthic imagery for marine monitoring and management.

2.5 Future need of IMOS AUV capability for collecting benthic imagery

All jurisdictions indicated they would still use the AUV to some degree if it were available, with Parks Australia needing access to capability generally, and the States indicating a need for the capability in deeper waters. All jurisdictions who could answer the question of co-investment of vessel time or other logistical capability, indicated that this would be likely/possible depending on future budgetary pressures.

Recalling that Parks Australia has no AUV or other benthic imagery capability of its own, monitoring of the AMPs remains a central use case for ongoing IMOS AUV deployments. In proposing a counter-factual scenario of having no future access to IMOS AUV capability, Parks Australia would likely be the user most impacted.

In other jurisdictions, the most specific area of future need for the IMOS AUV was joint Parks Australia/State deployments such as the Capes area in Western Australia and Kangaroo Island in South Australia. This indicates a potential need for IMOS AUV capability in the deeper areas of State reserves where they abut AMPs. This may also be the case in the deeper parks of Victoria.

It is noted here that while the Great Barrier Reef Marine Park requires benthic monitoring for management, the IMOS AUV capability has not been deployed in the region since 2015, with none of the repeat deployments occurring in the depth niche of 50-200m. Further, IMOS AUV deployments in south-eastern Queensland, near Moreton and Stradbroke Islands, are also in waters <50m.

Therefore, there is a niche in 50-200m as suggested in the External Review, but only for selected State locations and Commonwealth managed areas. It is noted, however, that should IMOS AUV capability not be available in the future, the States interviewed indicated that this would have a minor consequence for impact.

Availability of the IMOS AUV capability was seen as an opportunity to continue monitoring previously surveyed sites. Having noted earlier, however, that Parks Australia, Western Australia, and Victoria are still designing frameworks that include the use of benthic imagery, it is likely that AUV imagery would also be useful for the establishment of new baselines that are yet to be identified. All respondents considered surveys for new baselines may be a future priority, would have implications for future design of any IMOS AUV program, and

[5] See Doherty, P, (2021) 12, 16, 29, 35, 49.

[6] See capability statements from AIMS, CSIRO and QUT in the appendices of Doherty, P (2021).

would require careful management by a steering committee and the Facility manager. The application of the 'niche' would clearly play an important role in defining any new locations for deployments.

2.6 Conclusions

- While not yet explicit in management frameworks, most jurisdictions do, or will, require benthic imagery for monitoring of their marine environments.
- Many jurisdictions focus monitoring efforts on shallow benthic environments (<50m) and have developed capabilities to work in these depths. This is not the case, however, for the Commonwealth AMPs.
- In accepting these points, Parks Australia's monitoring of the AMPs becomes the main use case for the IMOS AUV.
- There are some areas of State jurisdiction that are proving too deep for the newer, cheaper, and smaller technology (e.g. ROVs), which could form part of a use case for the IMOS AUV capability.

3. Benthic Imagery

3.1 Context

Benthic imagery refers to the raw output of the IMOS AUV Facility or other benthic image capability. In the case of the IMOS AUV Facility, these are the un-annotated images taken by the IMOS AUV vehicle and which are uploaded into the IMOS Autonomous Underwater Vehicle Images Viewer. As noted in the External Review IMOS has a repository of 5,568,106 images in the database, most of which are not annotated.

3.2 The growth of benthic imagery collection

All jurisdictions indicated a need for benthic imagery analysis. With the stated increase in capability across most jurisdictions for benthic image collection, it is likely that image storage will become an increasing issue. As noted by the External Review, the labour-intensive pipeline that exists between the raw images and annotations is the bottleneck to producing useful benthic information.

3.3 Emerging technologies and issues for marine imagery repositories

When asked whether jurisdictions anticipated a reduced need for imagery in the future, most responded that while the scope and volume of images may shift, the need for benthic imagery would likely endure. One exception to this was Parks Australia, who indicated that new technologies may one day reduce the need for imagery.

Emerging technologies and methods for understanding benthic environments included the use of environmental DNA, remote sensing and advanced ROVs. However, there was a feeling that none of these technologies were at a place where they could currently replace benthic imagery from capabilities such as AUVs.

Further, and outside the scope of this Continuation Review, with various sovereign data security and integrity requirements of institutions that collect data (including images), there are increasing administrative burdens on the storage and handling of raw images across all data repositories. This can conflict with the FAIR (findable, accessible, interoperable, and reusable) principles. The sovereign capabilities, user registration, and other requirements from broader policies will likely need to be an emphasis for the IMOS AUV repository of images and other jurisdictional or institutional repositories that have linkages to the broader IMOS marine imagery structure.

3.4 Conclusions

- Interviews highlight the ongoing need for storage and analysis of benthic images.
- While new technologies are on the horizon, benthic imagery remains a core source of data for the management of benthic environments across jurisdictions.
- Not all benthic images are currently being annotated, but the images without annotations still require management and storage.

4. Image Annotations

4.1 Context

Image annotation refers to the act of identifying the features and species contained in the images. This turns raw imagery into useable data for management and research. The annotation of benthic imagery is identified as a bottleneck in the workflow of AUV-like capabilities, as it is labour intensive and time-consuming. This section examines the second key question of the Review Continuation; the end-user value of IMOS increasing investment in image processing.

4.2 The issue of annotations

There is a clear need for image annotation. Most jurisdictions indicated that they undertake annotation of images, either via institutional staff, staff at other institutes, or by students. Parks Australia indicated that they fund external researchers to annotate images. These researchers are then required to make the annotations open access.

Annotating images is time-consuming and this means few images are annotated relative to the number of images collected. Ideally, in the context of IMOS AUV-derived images, the annotated images are uploaded into the UMI sub-Facility for use by other researchers or managers. One respondent identified ongoing frustrations with uploading annotated images to Squidle+ and has instead begun uploading the images to a different repository on Amazon Web Services.

Jurisdictions all seemed willing to provide both images and annotations to open access repositories – and more specifically the UMI sub-Facility, with most citing time, resources, prioritisation, and technical issues as barriers to doing so. There appeared to be universal willingness and acknowledgement of the need to have open national repositories for such annotations, particularly in the event those annotations could contribute to machine learning in image analysis.

4.3 Artificial intelligence (AI)/machine learning and annotations

There is developing capability to apply AI to marine imagery to increase the speed and efficiency with which imagery can be annotated. Prominent examples of such efforts exist at AIMS and CSIRO.[7] Only one jurisdiction that was interviewed was using AI capability on a specific species of macroalgae, and this is not currently open access. Great Barrier Reef benthic images are assumed to benefit from AIMS' BenthoBox.

Respondents were aware of the broader efforts to increase AI capability in the marine imagery space, with several respondents noting that they provided marine imagery to various institutions (universities and AIMS) that were running AI programs, to improve and develop the various algorithms.

[7] See Doherty, P (2021) 47-48.

While AI is an emerging capability being developed at individual institutions, it is not yet at a stage of utility and use for broader marine imagery users across many jurisdictions.

The External Review recommended that IMOS consider options to expedite automated classification of benthic imagery (Recommendation 7), however, the above issues with loading annotations into Squidle+ and the clarity and purpose within the community around the importance of uploading annotations indicates that more work needs to be done prior to increasing investment in machine learning activities.

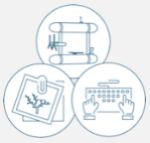
4.4 Need for access to vehicles vs capability to conduct AI on collected images

In gaining a clearer view of prioritisation of institutions between having access to a vehicle to collect images and the development of AI capabilities, jurisdictions were asked to decide between the two.

All but one respondent implied that one cannot exist without the other for their programs. When pressed, the AI capability seemed to be the reluctant priority.

4.5 Conclusions

- There is an end-user need for investment in image processing, however, this investment should be focused on getting the initial workflow between imagery and openly accessible annotations more widespread and reliable before focusing on machine annotations. One will help the other.
- Effort should be concentrated on gathering annotations before stepping into machine learning platforms and ensuring that the annotations provided are useful in the development of algorithms in the future.
- The sharing of annotations in the UMI sub-Facility will help both broader research and ultimately machine learning algorithms.
- It should be the role of the broader benthic monitoring community to foster a collegial and community approach to supporting the development of AI for the benefit of the Australian marine community.



5. Review Continuation overview and potential issues

The above discussions have concluded the following points, and in doing so have raised various issues:

5.1 AUV Operations

There exists a need for IMOS AUV capability. In applying the need and niche aspects of the two Reviews, this narrows the IMOS AUV user base to AMPs and some deeper State parks/areas of environmental significance.

Issues for further consideration, include:

- The need and niche have narrowed the potential user base, wherein Parks Australia would be the primary user of the IMOS AUV capability. This could have a flow on impact to benthic image availability and image annotations.
- Repeat benthic surveys in AMPs are currently concentrated in AMPs which are adjacent to Tasmania (9 of 14 repeat surveys conducted in all AMPs are in the South-East Network).
- If the accepted niche of operation is surveys in 50m – 200m of depth, then careful consideration, consolidation, and prioritisation should be given to the suite of existing repeat benthic monitoring sites. The majority of previous deployments would not, or only partially fit the proposed depth niche:

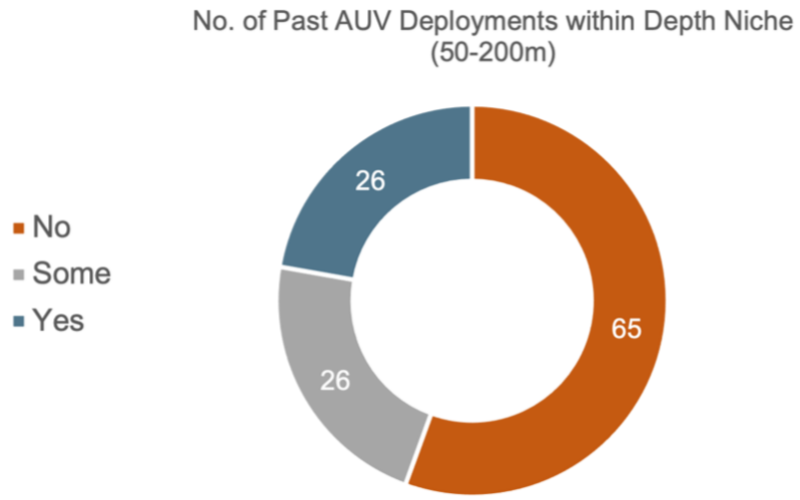


Figure 12. Previous deployments within the recommended depth niche.

- Access to vessels has proven difficult for the Facility. If a narrowed user base is realised, co-investment opportunities will require consideration.
- It was noted by one respondent that the smaller IMOS Nimbus AUV still needs a large vessel to deploy. This would need clarification within the community, with the Nimbus AUV having been launched from larger vessels such as the RV *Bluefin* (Tas) and RV *Ngerin* (SA), as well as the smaller RV *Noctiluca* (Tas) and RV *Bombora* (NSW).
- This review has drawn conclusions from jurisdictions who are undertaking reviews into marine management. While research utilising marine imagery can be taken up and used by managers without explicit pathways, the lack of explicit management frameworks decisively articulating the need for benthic monitoring across some jurisdictions raises the risk of IMOS collecting marine images that are not taken up and used for biodiversity conservation and management. This could dilute the impact of the investment made into this Facility and undermine IMOS' 'planning for impact' strategy.

5.2 Benthic imagery and image annotations

Benthic imagery and image annotations are dealt with together in this section.

With the proliferation of marine imagery from smaller vehicles such as ROVs, comes a greater need to ensure storage, access and processing of marine imagery. While new technologies are on the horizon to monitor benthic communities, quality benthic imagery remains a core source of data for the management of benthic environments across jurisdictions.

Image annotations form the data and usable information derived from the AUV capability, and with the developing AI capabilities emerging from Australian institutions such as AIMS and CSIRO, machine learning seems an inevitability. The approach from jurisdictions, however, indicates that AI is not yet at a level of maturity and accessibility that it could be easily taken up and used by the broader marine management and research community.

Issues for further consideration, include:

- The External Review recommended that IMOS consider expediting automated classification of benthic imagery, noting that only 5% of images from the Facility have been annotated.
- The Continuation Review revealed uploading of images into Squidle+ remains a barrier for some marine managers. This needs to be addressed to ensure annotations can be collated for use by other marine managers and researchers, as well as for the building of machine-learning algorithms.
- It is inevitable that the annotation of marine images will be automated via AI. Regardless of the immediate decision from this series of reviews, there exists a need to engage with AI developments, and to ensure

marine image workflows can eventually be utilised for the development and use of AI-based annotation repositories.