Marine Biodiversity Hub

National Environmental Science Programme

Progress towards a nationally integrated benthic biodiversity monitoring program for Australia's marine realm

Neville Barrett, Jacquomo Monk

Project D3 - Evaluating and monitoring the status of marine biodiversity assets on the continental shelf

June 2021

Milestone 11 – RPV3





UNIVERSITY of TASMANIA

IMAS INSTITUTE FOR MARINE & ANTARCTIC STUDIES

Enquiries should be addressed to:

Dr Neville Barrett,
Institute for Marine and Antarctic Studies, University of Tasmania.
Email: neville.barrett@utas.edu.au

Dr Jacquomo Monk,
Institute for Marine and Antarctic Studies, University of Tasmania.
Email: jacquomo.monk@utas.edu.au

Preferred Citation

Barrett N, Monk J (2021). Progress towards a nationally integrated benthic biodiversity monitoring program for the Australia's marine realm. Report to the National Environmental Science Programme, Marine Biodiversity Hub. *Institute for Marine and Antarctic Studies, University of Tasmania.*

Copyright

Acknowledgement

This work was undertaken for the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Programme (NESP). NESP Marine Biodiversity Hub partners include the University of Tasmania; CSIRO, Geoscience Australia, Australian Institute of Marine Science, Museum Victoria, Charles Darwin University, the University of Western Australia, Integrated Marine Observing System, NSW Office of Environment and Heritage, NSW Department of Primary Industries.

Important Disclaimer

Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

This report provides an overview of some key benthic biodiversity monitoring programs and datasets able to be utilised nationally to form the background to broader, integrated programs for reporting on the State of the marine environment, as well as supporting appropriate and standards-based inventory and monitoring within the Australian Marine Parks network. It includes an overview of the associated databases, that together with the background programs, provide a suitable framework for establishing and supporting a nationally-integrated monitoring program for the marine realm.

Over the past eight years there has been considerable progress towards national-level coordination, collaboration and reporting in the marine benthic biodiversity monitoring space, a key objective of the National Marine Science Committee plan 2015-2025. Several key datasets with national coverage have been collated and/or published, including underwater visual census (UVC), baited remote underwater video (BRUV), autonomous underwater vehicle (AUV), acoustic monitoring of mobile/migratory organisms and marine seabed mapping datasets. Considerable focus has also been undertaken by the NESP Marine Biodiversity Hub in the establishment of national working groups (e.g. AUV National Benthic Monitoring Group and BRUV Monitoring Group), and the development of national Standard Operating Protocols (Przeslawski & Foster, 2018) to ensure continued consistency in data collection efforts across platforms. Custom data discoverability and interactive web-portals have also been developed to allow for the exploration and sharing of fish (www.globalarchive.org and www.reeflifesurvey.com), habitat mapping (www.seamapaustralia.org) and multibeam sonar (http://ausseabed.gov.au) datasets, and new ones are being developed (e.g. the Australian Ocean Data Network national UVC database). Despite these efforts, some datasets remain uncollated, such as towed video and sled/grab samples, and to a lesser extent AUV annotations (although all AUV imagery is available on the AODN and viewable at (https://auv.aodn.org.au/auv/) and some annotations are stored on Squidle+.

Good progress has also been achieved in the development and trialling of some collated datasets for national level reporting. For example, State of Environment (SOE) reporting metrics have been developed for fishes based on UVC datasets (Stuart-Smith et al. 2016) and are currently being adapted for BRUV datasets (Monk et al. 2018). Likewise, the national benthic monitoring program based around the IMOS AUV facility has been developed with the aim of SOE reporting at local to national scales, but still requires a focussed effort to produce the first national analysis. One major limitation has been the availability of digital infrastructure for image-based platforms (e.g. AUV, BRUV, ROV) to allow image annotation and storage/collation/sharing of annotated imagery. Progress in this space has been rapid in the past five years for BRUV imagery with the development of Global Archive (www.globalarchive.org) for stereo video-based imagery annotations for mobiles species, and similar progress now needs to be made in the still-imagery space via platforms such as Squidle+ (http://squidle.org/) to allow similar sharing of imagery and annotations. It is anticipated that such development will not only facilitate progress towards more integrated benthic monitoring programs, but also rapid progress towards automation of image analysis, allowing for greatly improved and timely access to changes in key monitoring metrics, such as kelp cover, through time.

One substantial limitation yet to overcome for still imagery annotation is the potential range of different scoring approaches used by differing jurisdictions. As was the case with development of Global Archive, the future development of image annotation repositories will likely facilitate the discussions necessary to bring more standardised approaches to this field. This is currently being rapidly progressed by the UMI (Understanding Marine Imagery) project supported by IMOS/AODN.

It was not within the scope of this project to suggest the key elements required for a nationally-integrated monitoring framework (e.g. standardised methods, metrics, data products, data services, data stewardship, sustainable funding, governance, capacity building) as that is within the remit of the National Marine Science Councils working group on sustained monitoring. However, the methods, databases, standards outlined in this report do give significant guidance around the more advanced and widely used methods and approaches that have already significantly advanced the aim of developing a nationally-integrated monitoring program, and we suggest these form a core element of any collaborated and integrated program going forward.

1. INTRODUCTION

As a consequence of growing concern about the changing state of biodiversity, international targets have been agreed with the aim of bringing a reduction in the rates of loss (e.g. the Convention on Biological Diversity's Aichi Targets; http://www.cbd.int/sp/targets/). To meet Australia's international reporting obligations in this area, under initiatives such as CBD, SDG and OECD, national-level reporting is required that synthesises appropriate reporting by the Commonwealth and the States. Key to assessing the performance of management actions against such targets is the availability of sufficient biodiversity monitoring data (Butchart et al. 2010) and national-level coordination between research and management agencies. This need was recognised by the National Marine Science Committee (NMSC) and incorporated as key recommendations of their National Marine Science Plan 2015-2025 (NSMP) (https://www.marinescience.net.au/wp-content/uploads/2018/06/National-Marine-Science-Plan.pdf). For example, they recognised that biodiversity conservation and ecosystem health was a major challenge and therefore recommended that Australia establish and support a national marine baselines and long-term monitoring program and use this to develop a comprehensive assessment of our estate and to help managed Commonwealth and State marine reserves. In a similar and related development, the establishment of the Australian Marine Park (AMP) network and associated commencement of management plans in late 2018 brings both a need and an opportunity to develop a nationally integrated benthic biodiversity monitoring program within the network, one that ideally sits within a broader national framework that links State and Commonwealth initiatives.

The NERP and NESP Marine Biodiversity Hubs have been working with researchers and State and Commonwealth agencies (including IMOS/AODN) towards meeting the needs identified in the NMSP as well as those required for effective monitoring and inventory within the new AMP network. This has included (1) identification of platforms suitable for national-level monitoring and inventory, (2) working with stakeholders to develop Standard Operating Protocols (SOPs) for the more common platforms, (3) establishment of a common language for biodiversity and habitat classification from imagery (CATAMI), (4) facilitation of national working groups around key platforms (Multibeam sonar (MBES), autonomous underwater vehicles (AUVs) and baited remote underwater video (BRUVs)), and an annual MPA science/management forum, (5) engagement in development of key national database/annotation/data access/visualisation platforms such as Global Archive, Squidle+, AusSeabed, Seamap Australia and a new AODN database for UVC data (the UMI-Understanding Marine Image facility).

All of these steps have in some way addressed identified actions in the NMSP, including: (1) systematic exploration mapping and characterisation of our marine estate and for monitoring the condition of key assets, (2) bringing together existing data sets held by governments, agencies, universities and industries, (3) establishing methods and data standards for developing environmental baselines and long term monitoring, (4) providing a basis for reporting the state of the national marine environment and impact of cumulative pressure on high value systems. Progress in meeting these actions will be assessed in this report in the appropriate sections.

Typically, obtaining monitoring data for marine organisms is often a time-consuming and costly process, and because of this, our knowledge of patterns in their species diversity is generally poor. The degree of difficulty in sampling the marine environment also increases with depth. Thus, the intertidal, is relatively well understood, yet despite this, there are few long-term intertidal monitoring programs in place. The immediate subtidal, down to 30 m or so can be sampled and observed by SCUBA equipped researchers undertaking UVC or similar approaches (e.g. diver operated video (DOV)), and this zone is moderately well understood and the subject of a number of long-term monitoring programs (e.g. Sweatman et al. 2011). In the case of marine biodiversity monitoring, these are usually reef associated, and invariably are part of monitoring programs associated with marine protected areas. Alternatives to SCUBA have been developed in recent years for monitoring of demersal fish assemblages, with the most utilised method being stereo BRUVs. However, despite extensive spatial coverage, time-series in the stereo BRUV data is still sparse, with very few datasets spanning periods of up to a decade (https://www.nespmarine.edu.au/document/workshop-report-national-bruv-forum-%E2%80%93-perth-18-19-july-2017). In some jurisdictions, seagrass extent and condition has also been a focus of a number of monitoring programs, with these metrics typically being assessed via UVC and drop/towed video.

Monitoring at depths greater than 30 m has been relatively sparse in Australia to date, due to the increased difficulty and expense of sampling at depths beyond typical SCUBA depth. Many such studies are once-off sampling via platforms such as grabs and sleds and are typically for taxonomic description and collections rather than monitoring. Likewise, towed video has been widely used at such depths, but in many cases, this use has primarily been for habitat description or validation as part of mapping programs, rather than for biodiversity description or monitoring. A notable exception to this has been the use of Towed Video on deep-shelf, slope and seamount habitats from MNF vessels where the video systems and associated still cameras have been used for biodiversity assessment (e.g. Williams et al. 2015), although in most cases these are baseline inventory applications, with very little temporal monitoring to date.

Trawls have been relatively widely used for fish and prawn surveys, however, with a few notable exceptions (e.g. Andrew et al. 1997; http://www.cmar.csiro.au/npfmonitoring) these have rarely been used in a monitoring context, particularly for biodiversity. More recently, Autonomous Underwater Vehicles (AUVs) have emerged as an effective platform for monitoring benthic assemblages via still imagery, and with support from the IMOS AUV facility, a national network has been established over the past decade. Similarly, IMOS support has led to more effective monitoring of animal movements in coastal waters via the AATMS network tracking acoustically tagged species, and some more spatially restricted monitoring of plankton assemblages via the continuous plankton recorder program.

In almost all cases, platforms for deeper-water survey are expensive to purchase and deploy, resulting in comparatively less information being available for these regions of the marine environment. There is very little vessel capability and support for surveys in shelf waters, and deployments beyond the continental shelf edge require access to the MNF facility that is typically very limited. Many of the deeper-water platforms used to collect baseline data have been deployed in a non-standardised ways as methods have been trialled and evolved along with technology, all of which has repercussions when data is compiled for national-level reporting, hence the focus of the NESP Hub on developing SOPs for the more commonly used tools at the current state of technology.

This report summarises the current state of many of the biodiversity monitoring programs underway in Australia, the extent that they do, (or have potential to) fit into a national monitoring framework and have supporting infrastructure (including SOPs and common databases), and their current or future capacity to meet biodiversity monitoring requirements at a national scale for international reporting. It also includes developments in access and sharing of multibeam sonar and seabed habitat data, as these are generally essential for underpinning monitoring programs. It does not attempt to address the wide range of localised programs undertaken by universities or some State agencies that are not in widespread use (and therefore unlikely to be of value in national reporting), or remote-sensing of key habitat features (e.g. seagrass and mangrove/saltmarsh cover, giant-kelp surface canopy) as the primary focus is on methods applicable to offshore Commonwealth waters, and with a particular focus on AMPs. Likewise, it does not address the state of physical datasets (including parameters such as SST, chlorophyll, ocean currents), as despite these being critical covariates for understanding drivers of change, they were out of scope for this report.

With the increased collection of marine datasets around Australia there has also been a rise in the development of online data portals which aim to improve discovery, accessibility and reuseability of monitoring data the marine environment. An important realisation from this process has been the extent that there has often been insufficient standardisation of national or regional marine biodiversity monitoring and sharing of such information to be able to adequately report at national scales (Pereira et al. 2012; 2013). However, with recent progress in digital mobilization of biodiversity datasets and improved data collection standards (e.g. Przeslawski & Foster, 2018) there is significant scope to move forward in supporting a range of standard approaches and supporting data portals, and to improve this for platforms that show future promise. Here, we provide an update and overview of the key biological datasets and associated national databases that provide suitable data for establishing a nationally integrated monitoring program for the marine realm.

2. BENTHIC BIOLOGICAL DATASETS OF AUSTRALIA

2.1 Baited remote underwater video station (BRUVs) datasets

Like most video-based methods, BRUVs are a relatively recent development, made possible by the miniaturisation and increasing affordability and resolution of video systems. By videoing a bait bag in front of stereo camera systems (where stereo has been used), they target bait-attracted fish species and are able to provide an estimate of fish species abundance and size structure. Since the year 2000, > 20,000 BRUV deployments had been collated from continental shelf waters around Australia by early 2019. These deployments provide samples of at least 2,694,000 individual fish and more than 660,000 length measurements from around 1,900 species (Figure 1). Most sampling has focussed on spatial replication rather than temporal, and with the majority of datasets being collected in water depths of 0-50 m; despite specifically engineered BRUVs being capable of being deployed up to 2000 m depth (e.g., Zintzen et al. 2012) (Figure 2). Accordingly, most reporting associated with BRUV datasets will likely be constrained to depths < 100 m, at least until deeper programs develop within areas such as the new Australian Marine Park network. A full description of the data can be found at Harvey et al. (2021).

While the BRUV dataset spans nearly two decades, time-series datasets are very restricted at present, with the majority of deployments being associated with initial baselines and spatial research in biodiversity or fisheries applications. The extent and nature of these datasets was examined at a NESP Hub sponsored workshop in 2017 that aimed to review the extent of BRUV coverage and establish a National BRUV working group to coordinate development of steps towards a nationally integrated approach to BRUV-based monitoring, including adoption of SOPs (https://www.nespmarine.edu.au/document/workshop-report-national-bruv-forum-%E2%80%93-perth-18-19-july-2017). That workshop coincided with the development of Global Archive, a database and visualisation tool developed specifically for holding and sharing BRUV datasets. Global Archive was initiated by Tim Langlois (UWA) with support from Australian Research Data Commons (ARDC) and Australian Ocean Data Network (AODN). It is described in more detail in a following section, however, its use at the workshop was invaluable in being able to explore the spatial and temporal extent of BRUV deployments around Australia, including the extent that BRUVS had been deployed for baselines or monitoring. It allowed major gaps in spatial coverage to be identified, as well as developing our understanding of the extent that monitoring programs were adopted my major research agencies.

A major outcome from the workshop was the realisation that developing a nationally integrated BRUV-based program will require more effort to develop a generally agreed adoption of SOPs, as historically many major organisations had differing survey methods. This has included the use of mono vs stereo (so not possible to get size estimation), differing deployment times, differing focus on length vs size estimation (some have not identified fish size, some identified only target species, some estimated all fish), and differing bait types. Overall, the establishment of the working group and development of Global Archive paved the way to improved national coordination, collaboration, use of common standards and data sharing. A substantial amount of the national BRUV data is now in Global Archive although issues are still to be resolved around data availability and access as some of the data is currently embargoed under confidentiality agreements. Despite this, it is likely that this information will become available after embargo periods are over, and the uptake and use of this information will encourage others to make their data available as well, including private consultancies.

Table 1. Summary of BRUV datasets available as of 2019.

State	Number of Deployments	Temporal coverage	Purpose
Western Australia (Various Universities and State Gov. Agencies)	10,376	Abrolhos Islands region (9 years) and the Kimberley (5 years). Other locations include Jurien Bay (3 years in deep water), Ningaloo (3 years), Canning Bioregion (2 years), Ngari Capes (2 years), and Rottnest Island (3 years).	Majority associated with baselines and biogeographical/fishery research, there is an increasing trend towards monitoring, particularly for MPAs or fishery purposes.
North-west Western Australia/Queensland (Australian Institute for Marine Science; AIMS)	3,317	None. Noting some time series is available at Ningaloo collected by university and state agencies	AIMS BRUVs data has primarily focussed on baseline descriptions of fish assemblages rather than monitoring, so currently there is very little time series data available.
Northern Territory (Territory Fisheries Agency)	73	None	Focussed on assessment of fish protection areas and limited to single sampling events.
New South Wales	2,432	Extensive time series sampling (up to 7 years). Temporal replicates at two-year intervals since 2010.	Focussed on baselines and trend towards monitoring, particularly for MPAs.

State	Number of Deployments	Temporal coverage	Purpose
Victoria	991	Temporal replication currently limited to Warrnambool, where there is a 3-year dataset.	Focus is around baselines rather than monitoring, and the focus has not been on MPA monitoring. However, there is an increasing interest in BRUV-based monitoring, particularly for State MPAs in deeper waters beyond those sampled in Victoria's long-term scuba based UVC monitoring program (5-10 m).
South Australia	877	A limited series of monitoring-based surveys across 2 years focussed around a subset of MPAs via Department of Environment, Water and Natural Resources (DEWNR). Flinders University has a limited set of data in a few locations with up to 3-years of data, and some locations with seasonal sampling.	Majority associated with baselines and biogeographical/fishery research, there is an increasing trend towards monitoring, particularly for MPAs or fishery purposes.
Tasmania	502	A single temporal (2 years) dataset has been obtained for the Governor Island Marine reserve.	Majority associated with baselines and biogeographical/fishery research, there is an increasing trend towards monitoring, particularly for MPAs or fishery purposes.

2.1.1 Future potential and challenges for monitoring using BRUVs

Through the work undertaken to date, BRUVs have been demonstrated as an effective tool for tracking the trajectory of a component of benthic fish assemblages, particularly site-attached, bait-attracted reef fishes, that are often the target of fishing effort. In some jurisdictions (especially NSW) they are increasingly the tool of choice for monitoring fish assemblages in MPAs. In WA at least, they are also a tool used in a fisheries context to monitor a suite of targeted reef fishes. In addition to this monitoring role, they are also used more widely in baseline inventories and for biogeography studies. While many of the earlier studies were somewhat experimental, developing gear and techniques and determining what was possible, there has been an increasing convergence in recent years towards a set of agreed SOPs that will allow national level comparison and collaboration. The SOP approach not only includes standardisation of deployments, but also now include effective monitoring designs that allow for robust comparisons to be made.

The overall level of collaboration has been greatly enhanced by the development of Global Archive as a national data repository, and by the establishment of a national BRUV working group to facilitate cooperation and integration of State and Commonwealth programs. With the implementation of the new Australian Marine Park network and associated need for network monitoring and evaluation, there is significant opportunity to deploy BRUV-based inventory and monitoring of cross-shelf habitats as a key component of a national standard approach. This would provide a framework to develop a more widespread and integrated approach that also incorporates off-reserve monitoring in Commonwealth waters as well as linking with the many State-based initiatives that are often focussed on MPAs. Examples of this have already arisen, where monitoring in State MPAs in NSW have been integrated into monitoring in the Hunter AMP, and baseline surveys in WA are linking State and Commonwealth programs in Ningaloo and the Ngari Capes/SW Corner Marine Parks.

The most significant challenges to a nationally integrated BRUV program are related to funding at both the State and Commonwealth level with respect to maintaining a time-series that is applicable for national SOE reporting requirements, and to fill spatial gaps that are not covered by MPA programs. Historically it has been MPA monitoring programs that cover the bulk of monitoring of marine biodiversity values in Australia, and support from other agencies will be required to support future off-reserve coverage away from MPAs and associated reference sites.

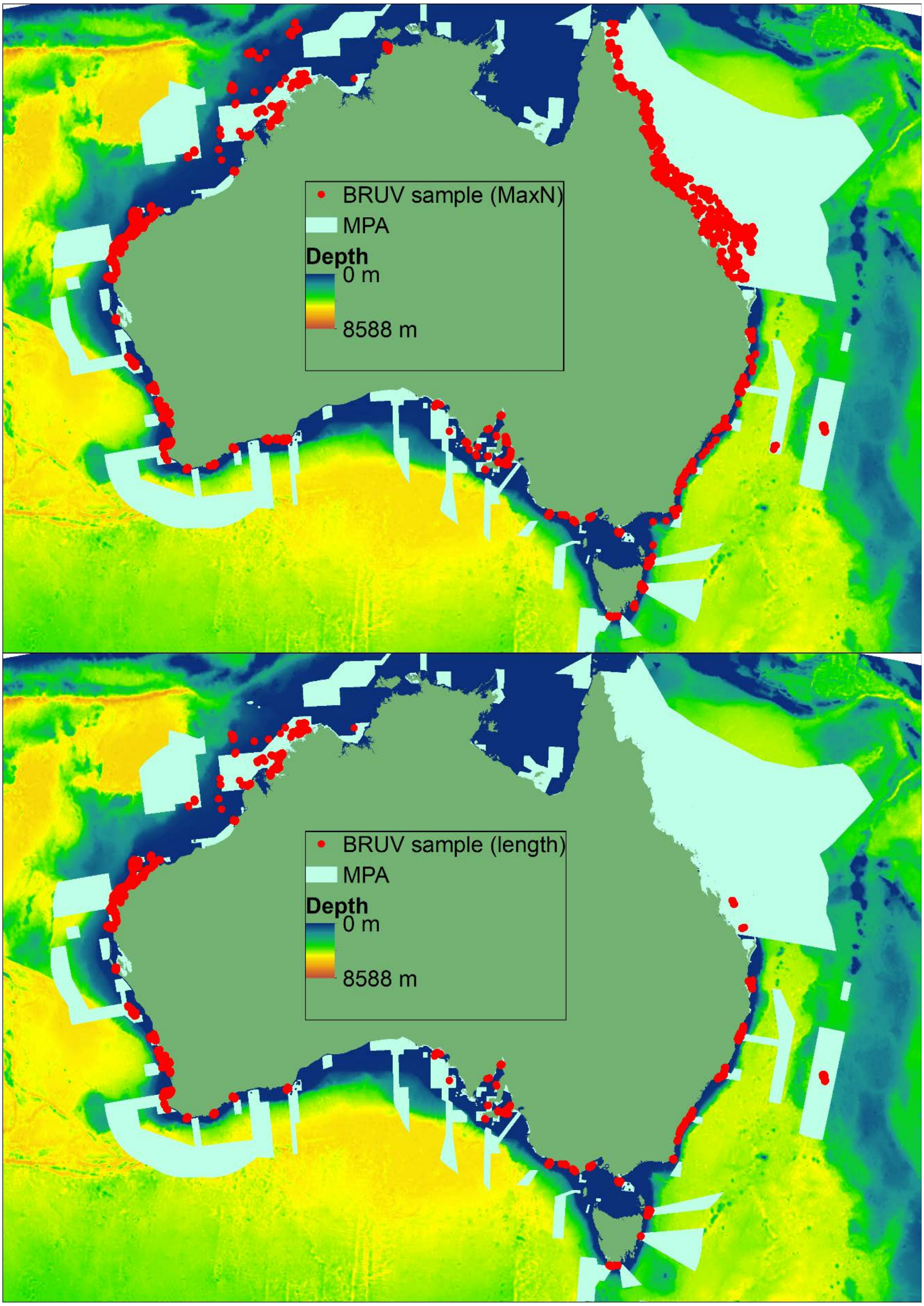

Figure 1. Location of BRUV sampling currently collated in Global Archive for MaxN (top) and fish length estimates (bottom) relative to Australia's network of State and Commonwealth marine parks.

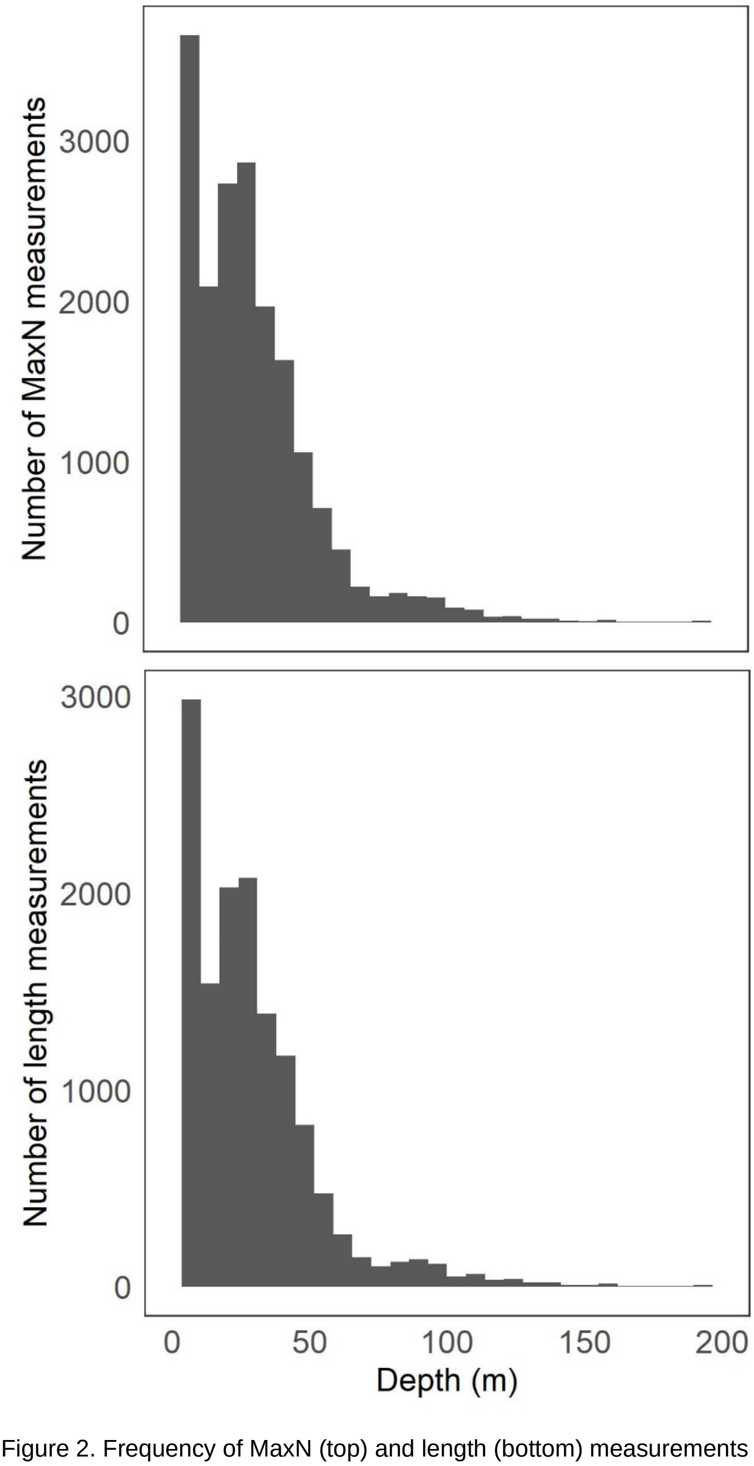

Figure 2. Frequency of MaxN (top) and length (bottom) measurements from BRUV samples across the continental shelf depths.

2.2 Autonomous Underwater Vehicle datasets

Autonomous underwater vehicles provide an ideal platform for deploying underwater imagery at depths beyond typical diving depths, and for extended durations. This imagery is ideal for quantitatively describing the cover of sessile benthic cover (algae and invertebrates such as corals and sponges) and overall habitat description. In Australia, this is currently the primary use of AUV platforms in a monitoring context. However, other applications are possible, and have been trialled, including description of benthic fish and mobile invertebrate assemblages, and addition of video cameras to survey assemblages of epi-benthic fishes. IMOS has supported the adoption of AUV-based monitoring, with initial trials in 2007 being developed into a more formal program from 2008 onwards. Approximately 5 million images have been captured across 663 AUV deployments around Australia over this period (Figure 3). With exception of the Northern Territory, there is now some degree of AUV coverage in most States and Territories, as well as in adjacent Commonwealth waters. Most of the AUV deployments have been undertaken by the IMOS AUV *Sirius* (based at the University of Sydney), which has been deployed to depths in excess of 300 m as part of the program, demonstrating its capability to undertake surveys on the upper slope, as well as shelf conditions. Despite this depth capability, the majority of images have been captured in 0-60 m (Figure 4) as most support for the AUV initiative has come from State-based agencies involved in monitoring of coastal waters. A more limited, but expanding, number of surveys have involved greater depths and in mid to outer shelf locations as part of inventory and monitoring programs being developed in the Australian Marine Park network. Currently this work has focussed on the Beagle, Flinders, Freycinet, Lord Howe, Huon and South-west Corner, Tasman Fracture AMPs.

Deployments of the IMOS AUV facility are guided by the Benthic Ecology Steering Committee and national SOP (Monk et al. 2020; https://auv-field-manual.github.io/), with the aim of providing an over-arching national program using standard approaches for monitoring and reporting. The central focus has been to deploy a standardised transect and replicate design on coastal reef systems. Where possible, this design was intended to provide coverage of reef systems with a broad transect design, with multiple replicates at local scales, replicates at a range of cross-shelf depths, replication in/out of MPAs, and replication at regional scales along eastern and western coastlines. New programs in Victoria and South Australia are just commencing to establish locations along the southern coastline.

An initial synthesis of the data generated by this program was published by Bewley et al. (2015) as a first step towards making annotation data derived from this imagery widely available.

To date, the most temporally mature monitoring data from the AUV facility can be found in Tasmania's east coast, with up to 6 repeat transects around the Freycinet region spanning 2009-2016. Temporally-replicated monitoring has also been completed at Morton Island (QLD- 3-5 yr), Rottnest Island (WA 4 yr), Abrohlos Islands (WA- 4 yr), Ningaloo (WA- 3 yr), Flinders AMP (Tas- 3 yr), Batemans MP (NSW- 2-3 yr), Huon AMP (Tas- 3 yr), Beagle AMP (Tas-2 yr), Port Stephens (NSW- 2 yr) and Jurien Bay (WA- 4 yr).

Despite the temporal nature of the IMOS-supported program, there has been little analysis of temporal trends from monitoring programs to date, primarily because of the limited time-extent of data so far, as well as restricted availability of funding/staff to analyse the available imagery. Initial time-series analysis has focussed on aspects such as indicator species and power to detect change through replication (e.g. James et al. 2017; Perkins et al. 2016; 2017). One nationally-focussed study (Marzinelli et al. 2016) examining patterns in kelp-cover, has demonstrated the utility of this dataset for national-scale reporting on a key biological metric, and it is likely that the next step is to repeat that analysis to provide the first temporal reporting at national scale from this program. More recently, Perkins et al., (2021) completed the first exploration of temporal patterns in benthic morphospecies from AUV imagery collected across several MPAs within the South-east Marine Park Network, finding that communities were generally stable over the survey period. However, several individual morphospecies were found to have undergone significant change.

An initial limiting step for analysis of AUV-derived imagery was the availability of appropriate image-scoring software, which restricted the ability to share data, as differing agencies were using variety of different image-scoring platforms and classification schemes. The development of the CATAMI-classification scheme partially resolved one component of this, as did the advent of a range of compatible image-scoring platforms, including Squidle+. The latter program has been developed as a repository of image-annotation data, as well as a scoring platform in itself, and will collate annotations from a range of different platforms and classification schemes, allowing cross-comparison of datasets.

At this stage, however, not all annotation data is captured in Squidle+ and hence available for analysis at national scales. This is partially because this platform has not had funding support in recent years, and partly because, without having a basal, shared morphospecies library for differing agencies to share and work from, most annotated data loses a lot of the necessary taxonomic resolution necessary to support robust analysis across datasets. It is important to note that since last year, funding from IMOS (under the 18-month investment for the Understanding of Marine Imagery initiative) is supporting the further development of Squidle+ as an annotation and sharing platform (including ingestion of new image sources) as well as ingesting legacy annotation data.

A core element of the Squidle+ database is to ensure all manual (expert) annotation of imagery is captured and able to be shared, as well as matched back to the original imagery to facilitate future steps towards automation of this process for key reporting metrics such as kelp cover, coral cover, sponge cover, and various sub-components of each based on morphology or factors such as health (e.g., coral bleaching, live/dead coral).

One other limitation for continuation of time-series has been the availability of an AUV able to be deployed cost-effectively from relatively small vessels. With the loss of a number of State or agency-based coastal vessels, there has been reduced availability to support the current AUV “Sirius”. This has recently changed with an additional new “Nimbus” AUV, allowing time-series in WA, Tas, and NSW to be continued in a renewed program.

2.2.1 Future potential and challenges for monitoring using AUVs

As stated above, it is likely that the IMOS AUV facility will have significantly increased uptake now that the new “Nimbus” platform is operational. The current national program has demonstrated the utility of this platform for monitoring benthic cover on reef habitat in a wide range of cross-shelf locations, as well as its potential for expansion into a range of other habitats from seagrass to soft sediments. Cost reductions associated with deploying the new vehicle will likely see sufficient uptake nationally to require development of at least one additional vehicle in the near future. There are no off-the-shelf alternatives currently on the market.

Development and support of agreed databases for sharing and visualisation of images and annotations is currently the most pressing need. This need is currently being met through Understanding of Marine Imagery initiative via IMOS/AODN funding, which is incorporating a significant upgrade of the Squidle+ tool. While this initiative has 18-months of funding, the platform will need longer term funding to support sharing and common use of a morphospecies library/reference image set, as without it, reporting at anything other than a local-scale will be restricted to broad-level CATAMI categories rather than finer-scale biodiversity metrics.

There are still some major gaps in the biogeographical distribution of AUV-derived imagery, including much of northern Australia and the GAB to SW Capes region, and in many regions, waters beyond State boundaries. These gaps and opportunities were identified in a review of the IMOS AUV program by the Benthic Ecology Steering Group in 2016, with the aim of guiding IMOS investment in this space in the future. It is certainly anticipated that reduced costs and improved ease of deployment of the “Nimbus” AUV will assist in filling these gaps, as will likely uptake by future inventory and monitoring programs within the AMP network. However, as is the case for most other biodiversity-based monitoring programs (e.g. BRUV, UVC), the majority of deployments are related to MPAs and adjacent reference areas, and additional effort is required to build the program to include regions where there is a significant spatial gap between MPA-based programs. Recent NESP-Hub facilitated surveys at Elizabeth and Middleton reefs (NSW) (2020) and the SW Capes MP (WA)(2021) have been significant new advances in improving this spatial co

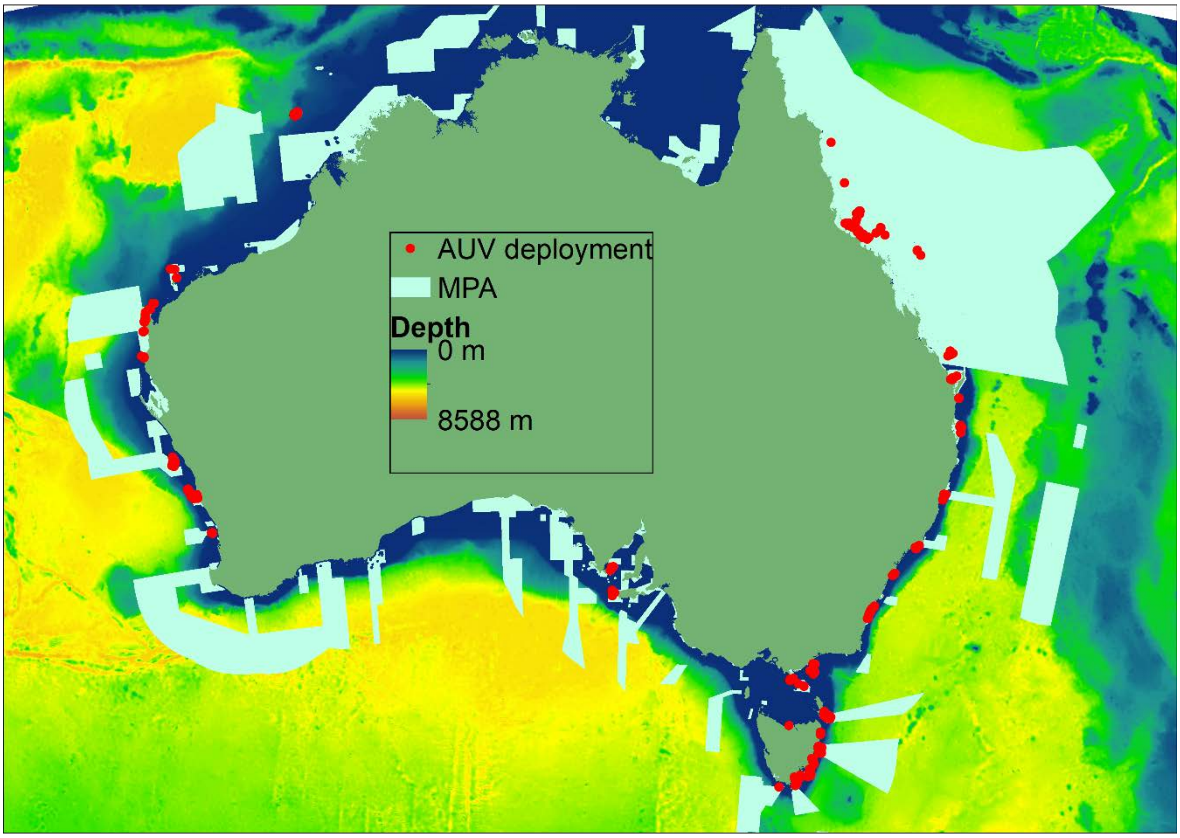

Figure 3. Location of AUV deployment currently collated in Squidle+ relative to Australia's network of state and Commonwealth marine parks.

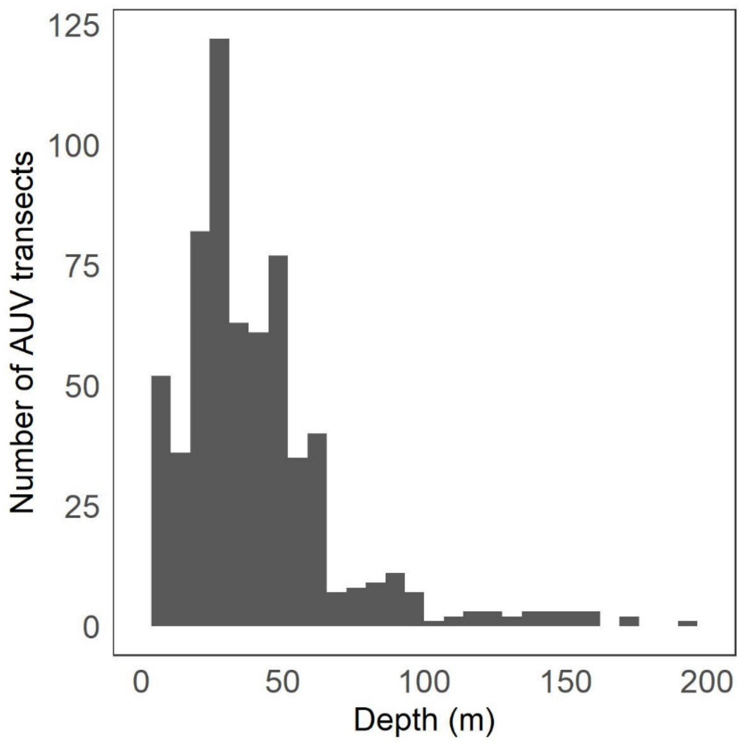

Figure 4. Frequency of AUV deployments (to 2019) across the continental shelf depths.

2.3 Towed Video datasets

Towed video has been used in a wide range of applications in inventory and monitoring programs around Australia. In most applications this involves use of video alone, but in others (including CSIRO/MNF camera systems) it can also include addition of downward or oblique-facing still camera systems. Typical uses include benthic habitat mapping validation and classification, coarse level description of benthic assemblage type and distribution, and to a more limited extent, finer-level benthic biodiversity description or targeted single-species distribution surveys (including epi-benthic fishes). However, until recently this has been significantly limited by camera resolution. For deep-water surveys, beyond shelf depths, towed-video and associated use of still camera systems has been the main tool for quantitatively describing the distribution of benthic biological assemblages, including descriptions to morphospecies (OTU-Operational Taxonomic Unit) level in many cases (e.g. Williams et al. 2015). While CSIRO-based surveys of deeper assemblages have involved a standard protocol for image analysis, and likewise a similar protocol used by AIMS in NW Australia, most video-based surveys from other agencies have utilised protocols specific to the task at hand, making any form of data collation and synthesis difficult to address national level analyses beyond the CRIRO and AIMS datasets.

As video-based approaches are relatively cost-effective and suitable for surveying cross-shelf habitats within the new AMP network, the NESP Hub worked with the national research community to develop a SOP for towed video platforms that would be suitable for AMP inventory and monitoring, as well as overall monitoring of the Commonwealth marine estate. While this SOP was completed in 2020 (Carroll et al., 2020; https://towed-imagery-field-manual.github.io/) in an effort standardise collection and annotation approaches, currently no shared national repository is available for annotation data. However, developments in two national data repositories (Global Archive and Squidle+) offer the opportunity and flexibility to incorporate habitat and biodiversity data derived from towed video, and further developments of these programs are intended to be based on the ability to incorporate such data as they evolve (See previous AUV and BRUV sections for details). An example dataset from the NESP Hub from Hunter AMP is currently accessible through Squidle+, but no annotations have been completed to date.

2.3.1 Future potential and challenges for monitoring using Towed Videos

To some extent there is a blurring of boundaries around the nature of towed video and the capabilities built into these systems, as they may be pure video, or incorporate still imagery as well, and ROV-based approaches are essentially an evolution of this but with better bottom-tracking capability. With improvements in video resolution and ability to better track seabed features (ROV approaches in particular), plus the addition of stereo systems for size estimation, towed-video (or similar) offers significant cost-effective approaches to monitoring of benthic assemblages, including fish in some applications, particularly in depths greater than 100 m. The most significant challenges for incorporation of these approaches into a national monitoring and reporting framework relate to encouraging widespread uptake of SOPs across jurisdictions, and encouraging use of national data repositories, with comparable annotation being undertaken to appropriate taxonomic level for common reporting. Ideally further development of Squidle+ (under the UMI initiative or similar) would incorporate capacity to store and share these annotations and utilise a common (nationally curated) morphospecies library (OTU) for consistency across datasets.

2.4 Sled and grab datasets

Sled and grab-based sampling methods are commonly used as a way of collecting biological and sediment samples from the seabed. Typically, they collect a range of sessile flora and fauna living on the seabed (e.g. sponges, bryozoans, molluscs etc), and in the case of grabs, they can also sample a component of the infauna living within sediments (e.g. polychaetes and bivalves). Most commonly, they are used in qualitative surveys associated with biodiversity description and are associated with museum-based collecting. The significant benefit of these methods is that sample species can be collected, and fully identified to species level. The main disadvantage is that they are destructive approaches, and require a high level of taxonomic skill, hence they have traditionally been more associated with initial inventory programs rather than monitoring. Despite this, there are several examples of localised monitoring programs, usually associated with assessing the impact of nutrient enrichment on infauna in estuaries or sheltered waterways (e.g. salmon farm impact assessments in Tasmania, Ross and MacLeod 2017).

Future potential and challenges: While museums are increasingly digitising their collections through, for example OBIS (http://iobis.org/) and ALA (https://www.ala.org.au/), there is currently no formal national repository of sled and grab datasets. Most datasets sit with individual museums or research agencies, with the species record then being visible to the wider community via OBIS or ALA. While this is effective for examining species distributions, it is not matched by a sample ID (i.e. information on the individual deployment to match with other species records or plot the distribution of sampling effort) or other related data to better understand the distribution of sampling effort, and the extent of presence/absence information. Hence it is currently difficult to accurately map the present status and distribution of sampling effort, other from data collected as part of MNF voyages where copies of all survey data are lodged with CSIRO and can be discovered by CSIRO's "data trawler" or the "ARMADA" web-viewer, although the latter is a static, and unsupported demonstration platform.

The NESP Marine Biodiversity Hub worked with the national research community in 2018 to develop an agreed national SOP to further standardise collection and identification approaches from sled and grab methods (sleds: https://sleds-and-trawls-field-manual.github.io/, grabs: https://grabs-and-boxcorers-field-manual.github.io/). While this SOP was not directly connected with a specific national database, future developments in the national data repository space (e.g., a database structure similar to Squidle+ or the national UVC database being developed by AODN) could readily accommodate such data if there was a driver for this through the AODN process.

2.5 Underwater visual census datasets

Underwater visual census datasets represent the largest inventory and long-term monitoring datasets for Australia's shallow reef (~10 m) communities, providing high taxonomic resolution for tropical and temperate fish, invertebrate and algal species. These include: 1) the Australian Institute of Marine Science Long Term Monitoring Program on the Great Barrier Reef (AIMS LTMP; 276 sites, 26 yr); (2) Reef Life Survey (RLS; 1,294 sites, up to 9 yr) with sites distributed on reef systems around Australia; and (3) the University of Tasmania's Australian Temperate Reef Collaboration Program (ATRC; 182 sites, up to 30 yr), a collaboration with most temperate States with a focus on monitoring State-based MPAs and adjacent coastal areas. Combined, these datasets provide national coverage of shallow reef communities (Figure 5), typically at depths or 5-10 m (Figure 6). They are also supplemented by a State-based program in Victoria utilising the ATRC methodology (up to 18-year time-series).

A significant advantage of many of these programs for national-scale reporting is that they were designed around a common SOP (e.g. ATCC and Victorian program), with the RLS program slightly altering that SOP to adopt it to the needs of volunteer divers. Essentially the core transect-based methods for surveying fish and mobile benthic invertebrates are identical but differ in that a quadrat-based approach for survey of macroalgae and sessile benthic species was used in the initial SOP and subsequently adapted to use of photo-quadrats for the RLS program to simplify field tasks and expertise required of volunteers. These broad biodiversity-based approaches differ more substantially with the AIMS LTMP which was initially established with the more specific focus of tracking crown of thorns starfish and their impact on reef systems in the GBR. For example, in the AIMS program, a subset of fish families and genera are recorded rather than the full assemblage, to reduce both the expertise required and the time taken per transect.

Due to the different methodologies utilised by these three major programs they are not fully cross compatible for national-scale reporting. However, core elements between programs do allow a select range of metrics to be compared, including targeted fish assemblages. Minor additions to programs such as the AIMS LTMP that add full fish diversity and size estimates at selected sites, could significantly enhance this compatibility through time if there was a desire for better integration of programs for national benefit. An initial analysis of the major programs at a national level for potential in SOE reporting was undertaken by Stuart-Smith et al. (2017), providing the first national scale quantitative analysis of marine biological data in this context, demonstrating the utility of such datasets for national-scale reporting of trends in biodiversity on reef systems.

While the analysis of Stuart-Smith et al. (2017) collated the existing data for analysis, there has been no central data repository for UVC-based data in Australia, with all major datasets residing on the database of the host agencies, and in need of significant updates to align them. This gap is now being addressed by IMOS/AODN and the NESP Marine Biodiversity Hub through development of the IMOS National Reef Monitoring Network (https://imos.org.au/fileadmin/user_upload/shared/IMOS_General/APM_2019_PRESENTATIONS/D2.12.pdf) and Understanding of Marine Imagery initiatives which provides the necessary support to bring in the existing datasets from ATRC, Victoria and RLS, and to more fully QA/QC the data (including photo quadrats). Given the similarity, it is likely that diver-held video (DOV) transect data from the DOV program in WA would also be suitable for this database, as well as emerging ROV-based data where ROVs are utilised for quantitative observations of fish assemblages.

2.5.1 Future potential and challenges for monitoring using UVC

Through the initial national-scale reporting on the SOE of reef fish assemblages, Stuart-Smith et al. (2018) demonstrated the capability of UVC programs to effectively contribute to national monitoring and reporting. This capability will be significantly enhanced with the current development of the national database and reporting facility. While the two core monitoring protocols (ATRC/RLS and AIMS LTMP) differ somewhat, there is potential to add some broader biodiversity focussed survey protocols at a subset of AIMS LTMP locations to enhance the comparability of these two core protocols for both monitoring of fish assemblages and mobile benthic invertebrates. Likewise, DOV-based approaches generate very similar data for fish assemblages, and incorporation of these datasets may be facilitated by the database developments and enhance reporting in locations where DOV programs are more common (NW WA), at least for fish assemblages that are the primary target of DOV methods.

For cover of sessile benthic biota, all main programs differ in their approach, yet are able to be compared for some key reporting metrics such as algal canopy/coral cover. It is not feasible to increase the level of taxonomic resolution of the RLS approach (e.g. photos can't see understory species of algae) to match ATRC diver-quadrat based approaches. However, the addition of photo-quadrats to the ATRC program would allow a much greater cross-compatibility of these datasets for many metrics important for national reporting, including cover of major algal canopy species and cover and health of coral.

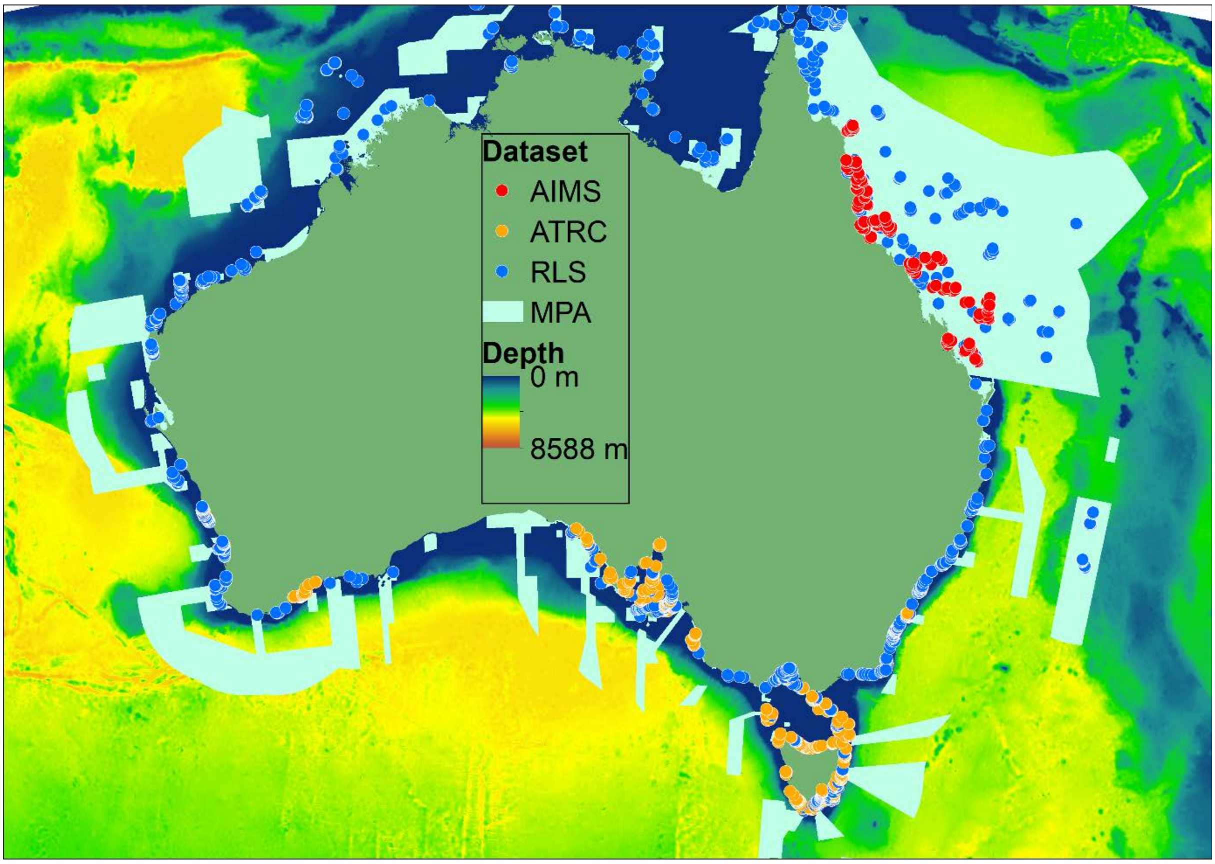

Figure 5. Location of UVC transects.

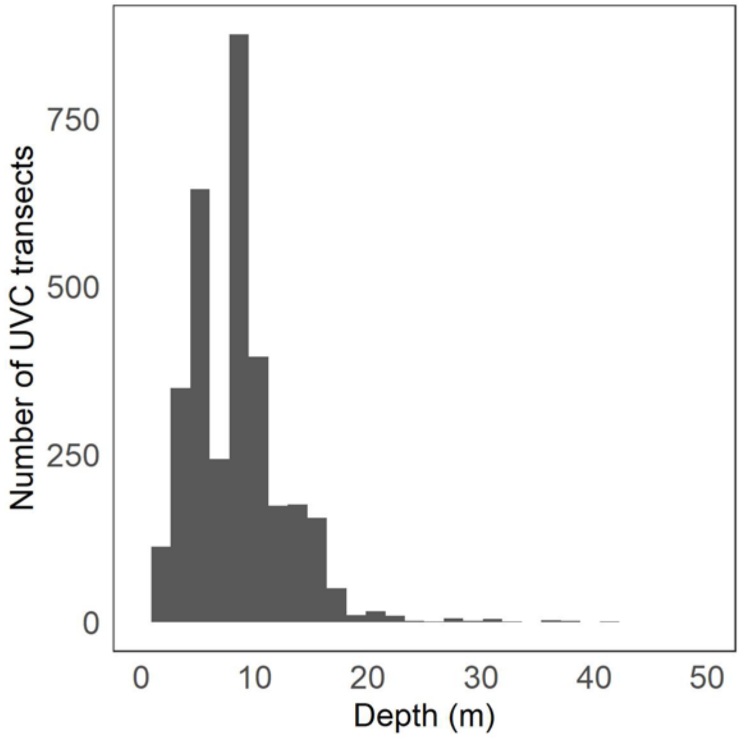

Figure 6. Frequency of UVC transects undertaken to 2019 across the continental shelf depths.

2.6 Animal tracking

Animal tracking provides a national coverage dataset capturing the movements mobile marine species. Over the last decade, the IMOS Animal Tracking Facility established a permanent array of acoustic receivers around Australia (Hoenner et al. 2018). Over this period a total of 94.7 million detections from 742 receiving stations have been captured for the 8,488 tags deployed on 147 marine species, including marine mammal, marine birds, state and federally listed species, fin fish and sharks and rays (https://animaltracking.aodn.org.au/). Hoenner et al. (2018) provide a detailed synthesis of this data, with a list of tagged animals and subsequent detections and time period of detections given as an appendix (https://media.nature.com/original/nature-assets/sdata/2018/sdata2017206/extref/sdata2017206-s2.pdf).

Progress is currently being made to make this data more openly available, with much of the data being made available via the Hoenner et al. (2018) data publication. Raw detection data is available up to 2021 via the AODN web-portal (Figure 7; https://animaltracking.aodn.org.au/).

2.6.1 Future potential and challenges for monitoring using animal tracking

The tracking network provides significant infrastructure for detecting the broad-scale movements of mobile species including listed species such as the great white shark and grey nurse shark. In a monitoring context the network has value in informing long-term temporal trends in the distribution of migratory species and improving understanding of the biological and physical drivers of these patterns. However, there are significant spatial gaps in the network for a national-scale coverage, and the receiver network requires significant funding to maintain its operability. It is important to note that there are other animal tracking projects (e.g., seals in Bass Strait; Arnould et al. 2015) that are currently not contained within the IMOS facility data that offer significant spatial and temporal coverage.

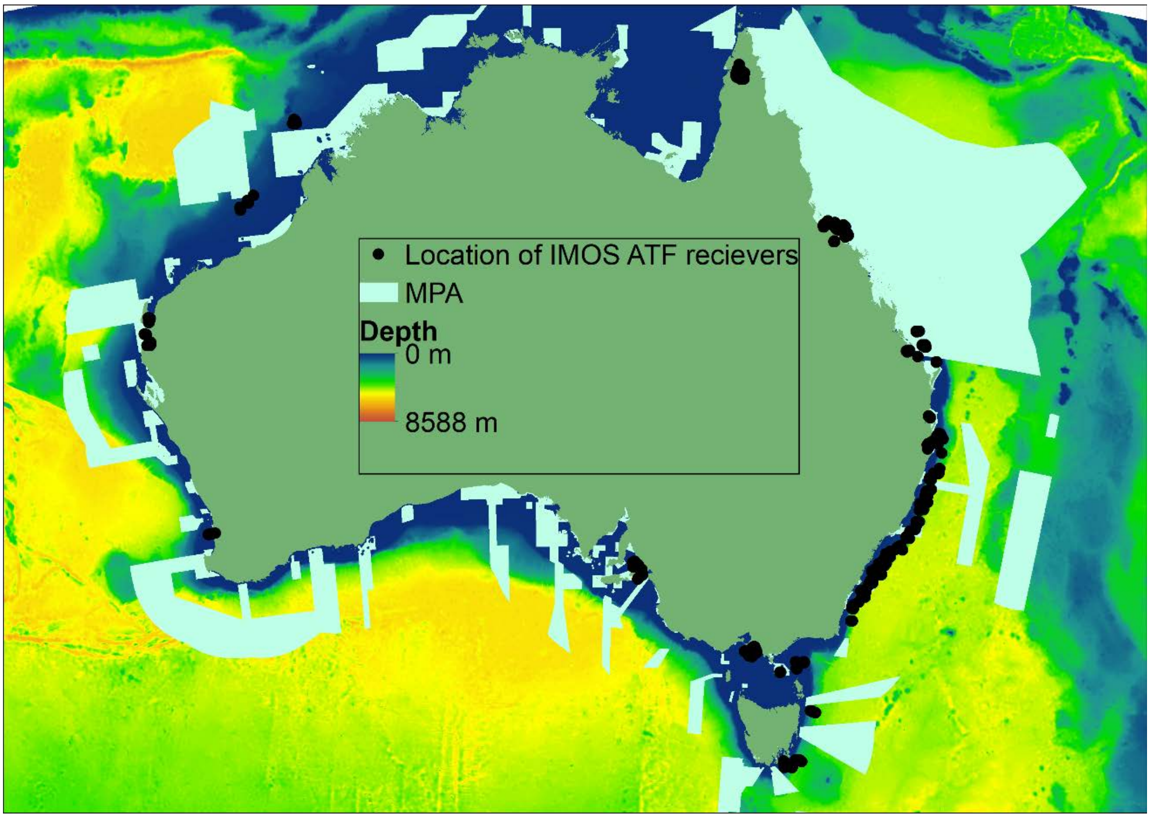

Figure 7. Locations of IMOS acoustic receiver array (for number of detections see Hoenner et al. 2018).

2.7 Seabed mapping

While not a direct part of biodiversity monitoring, knowledge of seabed bathymetry and habitat is a key element of understanding and predicting the distribution of biota, and mapping is usually seen as a core element underpinning most modern monitoring programs. Effective mapping not only enables specific habitat features to be targeted by inventory and monitoring programs, it is central to understanding the core drivers of variability in the distribution of biota within regions, as well as quantifying the importance or rarity of habitats and species. This is particularly the case for modern monitoring programs that use spatially-balanced sampling designs that are fully-representative of sampling regions rather than simply reflecting the biota at a set of chosen sampling sites.

This field has evolved significantly over the past two decades in response to major advances in acoustic technology, the ability to ground-truth seabed features using imaging technology such as towed video, and the ability to accurately map the position of features and boundaries due to advances in GPS. Hence, much available data is a complex mix of technologies and, with the exception of recent multibeam sonar methods, there has been no widely accepted SOP nationally. Despite this, much initial mapping was undertaken by State-based agencies using a mix of single-beam sounders, GPS, towed video and aerial or satellite imagery, although in some cases, in NSW and Vic in particular, more recent mapping has included full-coverage swath approaches as well. The results are typically polygon-based habitat maps of features including classified habitats (e.g. reef, sand, seagrass, mangrove, saltmarsh) and bathymetric contours. SeaMap Australia (seamapaustralia.org) developed by AODN, ARDC and IMAS, provides a national framework for the storage, access and visualisation of these derived habitat products, as well as a nationally consistent classification scheme, and ability to overlay a wide range of other spatial data available from Web Feature Services (WFS) enabled websites.

With the evolution of multibeam sonar technology, seabed mapping capability improved to allow full 3D coverage of the seabed. Major datasets have now been acquired by a range of national agencies including the MNF, CSIRO, Geosciences Australia, the Australian Hydrographic Office, AIMS, NESP Hub, and a range of State agencies, universities and private consultancies (Figure 8). A NESP Hub review of national datasets identified the lack of a national facility to deposit and share this data, and this has led to the development of the AusSeaBed program (http://www.ausseabed.gov.au/), facilitated by Geosciences Australia. Concurrently, to facilitate national coordination and collaboration in this space, a national SOP has been developed to standardise the data acquisition and post-processing pathways for multibeam sonar datasets (https://australian-multibeam-guidelines.github.io/).

2.7.1 Future potential and challenges for monitoring using seabed mapping

Significant progress has now been made towards the infrastructure necessary to support future mapping programs to underpin biodiversity monitoring, including SOPs for multibeam sonar mapping and the capacity to store and share this data. There are a range of major issues that still need to be addressed with multibeam sonar-based data, including managing data standards, data quality, data cleaning and further post processing, access to and visualisation of fine-scale raw data as well as ongoing and funding of the AusSeaBed program. However, despite this, there has been a quantum improvement in data access in the past five years in the habitat mapping/bathymetry space and this is likely to continue. If planned developments continue, they will include access to finest resolution point data via the data cloud, and ability, via a web portal, to generate appropriate-scale mapping products in selected regions of interest.

Likewise, with developments of related WFS capable websites, the two mapping-based programs (Seamap Australia for habitats, and AusSeabed for bathymetry and raw data) should provide the base platforms for visualising a range of imagery and spatially-related products for use in education and communication of many of the national monitoring tools and programs.

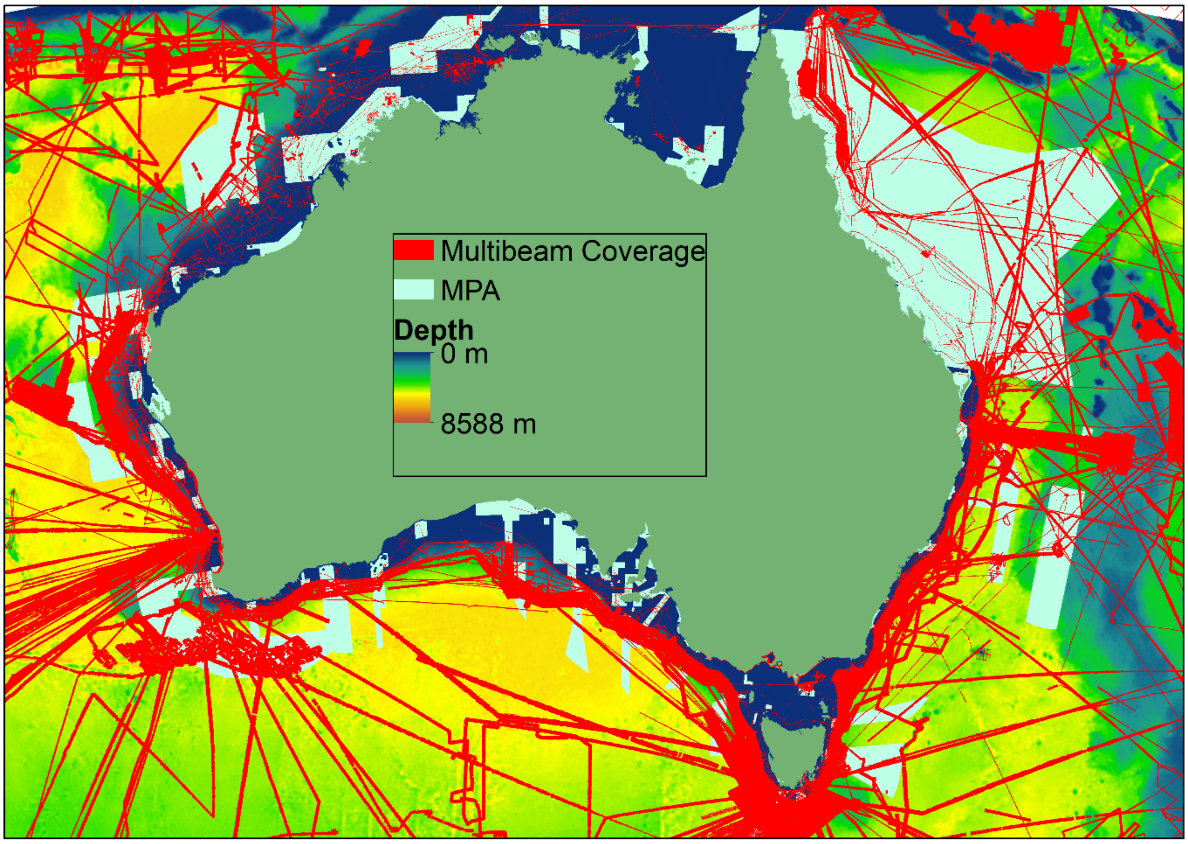

Figure 8. Coverage of national multibeam bathymetry as collated and displayed on AusSeaBed as of January 2019 (https://portal.ga.gov.au/persona/marine)

3. NATIONAL DATABASES

To enable national-level collaboration and data sharing, communication and reporting, it is imperative that major monitoring programs and monitoring tools are able to share final-stage derived data (at worst) and at best, are able to share all stages in the data-processing stream, including providing deployment metadata (site locations etc) ahead of inevitable data processing delays. For imagery, that would include sharing/storing raw imagery (or direct links to access that imagery), a shared annotation platform and classification scheme (e.g. from morphospecies to CATAMI), and shared annotated data. Currently no platforms exist that meet that criteria, however, significant progress has been made in recent years to meet that need. At present there are at least 14 databases that could qualify as frameworks or potential inputs into national databases (Table 1). These contain a wide range in the nature and quantification of data, ranging from structured sampling (e.g. GlobalArchive) to citizen science observations (e.g. Redmap).

For a number of the programs identified in earlier sections, developments are underway that meet most of the requirements needed to support a national monitoring framework, both for the tools used in those programs as well as future evolution of similar methods.

BRUV/ROV/DOV data: Global Archive (Table 1) now effectively supports the BRUV-based monitoring community as a repository of post-processed data for fish abundance and size. While not an image-annotation tool or video repository, it integrates closely with Event Measure Stereo software (used by the majority of the BRUV community) for the annotation stage, with the capability of storing links to original raw data held by institutions. Little further development is required at this stage to facilitate national data storage and collaboration. It also has the capability of being further adapted to capture fish survey data from ROVs (also annotated in Event Measure Stereo), as well as DOVs (also typically using Event Measure Stereo), hence can meet the needs of the monitoring community focussed on video-based methods for monitoring fish populations.

AUV/RLS imagery/Towed Video data: Squidle+ (Table 1) is currently being refined as the UMI (Understanding Marine Imagery) initiative (depending on IMOS/AODN support) that will primarily support most steps in benthic image-based monitoring of the seabed via the IMOS AUV program, RLS diver-derived imagery, and any current/future programs using imaging tools, such as ROVs or towed-video systems, including those with downward-facing still cameras (e.g. the MNF deep-water camera system). At this stage Squidle+ is able to be used for annotation of imagery and storage of derived datasets, however, due to the absence of a nationally shared morphospecies library, the data added to this at present, is unable to be analysed to a level equal to the finest resolution of the data generated by many monitoring programs. Refinement under the UMI facility is intended to rectify this issue. When completed, UMI will be able to be the ultimate repository of all national benthic biodiversity datasets derived from imagery. It will also be able to either allow direct annotation and image storage, or to link with external annotation platforms already in use by major agencies such as Benthobox (Table 1) developed for internal use by AIMS, or the MBI system currently used by CSIRO. Importantly, the current UMI initiative retains the location of all annotated points on imagery, and links with that imagery, to enable future automation of image classification by providing a training dataset. When refined, automated processes are likely to be a major component of national-level reporting in the future, particularly for readily identified components such as algal canopy cover, coral cover/health, and seagrass cover.

UVC datasets: The IMOS National Reef Monitoring Network data facility is currently in development to house national UVC datasets including RLS, ATRC (Table 1), and the

Victorian long-term monitoring program. Unlike the annotation-based databases above, most UVC data is acquired in-situ and hence no further post-processing is required. However, significant effort is required to store all attributes of these datasets without loss, and to enable standardisation of critical elements such as species names and size structures. This database will facilitate national-level reporting utilising three of the largest monitoring programs in Australia, with the potential to further incorporate data from the AIMS long-term monitoring program database (Table 1), as well as monitoring programs from other agencies. This facility will incorporate a range of automated reporting protocols that will further enhance the capability of real-time reporting on a range of metrics applicable for national-level SOE reporting.

Sled/Grab/Core/Trawl data: The Atlas of Living Australia (ALA), OBIS (Table 1) and GBIF, while not being databases in their own right, are data collation and visualisation portals that provide a tool to access biodiversity records from a range of platforms, including sleds and grabs, but also a wide range of platforms utilised by museums and research agencies, including UVC (e.g. RLS and the ATRC). They provide an essential access to national level biodiversity distribution records, but lack significant important information required for monitoring programs. For grabs and sleds (and similar sampling platforms (e.g. trawls) there is currently no national available database structure to deposit such data, particularly for important information on search effort, species abundances and individual sampling events. For example, there is currently no way to map the number of individual grab or sled sampling events, or to match biota records with individual sampling events (e.g. each “grab”). Without this information, there is no information on distribution vs sampling effort, and no knowledge on presence vs absence per sample, or indeed if sampling effort was targeted to particular species or more broadly-based. To facilitate national-level reporting/monitoring from such programs (e.g. under sled/grab SOPs), it will be essential to develop an appropriate data platform that can record and manage the essential elements required for effective monitoring.

Bathymetry and habitat data: New data initiatives including AusSeaBed and Seamap Australia are now providing national database capability for much of the mapping data that underpins biological understanding. Until recently there has been no national repository for mapping data in its various forms, including shapefiles of habitat distribution or multibeam sonar derived bathymetry and access to such data was very difficult. The AusSeaBed program now provides a common repository for anyone wishing to contribute multibeam datasets (from universities to national agencies) enabling visualisation of the spatial distribution of datasets and ability to identify datasets and download gridded data products. At present, only data products are available from the portal, rather than raw data, however, a planned evolution of this program is to be able to choose a spatial area of interest and either access all raw data within it, or be able to process the selected area at the data resolution required and generate a mapping product. Seamap Australia, while not storing raw data, provides a platform to store, access and visualise seabed habitat data, including contoured bathymetry. In many cases this includes validated habitat distributions derived from State-based mapping programs. Its architecture allows the visualisation of a wide range of spatial datasets available from other websites, including, for example, mapping distribution polygons from AusSeabed, and the known distribution of shelf reefs (NESP Hub).

Table 2. Open access datasets and programs of significance to a national integrated monitoring program. While not comprehensive, the programs listed below comprise the majority of available data with potential to inform benthic biodiversity monitoring at a national scale.

Name	Description	Species	URL
Squidle+	An open-access platform for storage and annotation of still imagery. Also includes annotation schemes, crosswalks between schemes, and the ability to undertake manual and automated image annotation. It is incomplete, and it is not supported for end-users at present (i.e. no funding for support staff), however, it is likely that IMOS will support further development in 2019/20 to ensure this tool is capable of being a national archive for annotated imagery, as well as an effective annotation tool in itself. That support will be via the IMOS AUV facility and bring Squidle + under the IMOA/AODN umbrella.	Benthic organisms annotated at a range of taxonomic levels including: Species and morphospecies, up to habitats and biotopes	https://squidle.com.au/
Benthobox/ReefCloud	BenthoBox/ReefCloud platform is designed to process images of benthic habitat with various levels of automated assistance and store these annotations. BenthoBox/ReefCloud is like Squidle+ in that it is enhancing ecological reporting by facilitating analysis of more imagery at a faster rate and at a finer scale than previously possible. It identifies the contents of hundreds of thousands of seafloor images, enabling biologists and ecologists to better understand and determine indicators of seabed health, including changes in the density of flora and fauna. It is currently being developed by AIMS as an internal tool rather than one used by the wider community.	Benthic organisms annotated at a range of taxonomic levels including: species, morphospecies, habitats, biotopes	http://benthobox.com/data/ https://reefcloud.ai/index.html#section-top

Name	Description	Species	URL
Global Archive	GlobalArchive is an online platform for the storage and sharing of annotated marine and freshwater fish fauna with a specific focus on video techniques at present. It has been currently configured for BRUV imagery and the multiple variations around that (stereo, mono, vertical, horizontal, bait types, extent of species scoring and length estimation etc). Despite the focus on BRUVs, it could be adapted for storage of other video-based methods that focus on fish, including DOVs, ROVs, and Towed-video. It is a storage/sharing/reporting platform only and does not play a role in annotation. Currently annotation is typically first undertaken in the SeaGIS program Event Measure stereo.	Currently contains 2.6 million records of individual fish and 660 thousand length measurements from 1,888 marine fish species with data from tens of thousands of BRUV drops around Australia from contributors including UWA, AIMS, Curtin Uni, Deakin Uni, University of Adelaide, WA Fisheries, IMAS (UTas), CSIRO, NSW DPI.	http://globalarchive.org
Reef Life Survey	Reef life survey is a worldwide citizen science program that engages volunteer SCUBA divers to record marine life on coral and rocky reefs, using standardised methods. Data for fishes, mobile invertebrates and substrate cover (photoquadrats) is stored in a specialized database and is available via the RLS website. That data is also distributed to a range of other sites that harvest the data, including ALA and GBIF (below).	17 million observations, covering 5291 species from 11,524 surveys at ~5000 sites, from 53 countries	https://reeflifesurvey.com
ATRC	The long-term temperate monitoring program now renamed the Australian Temperate Reef Collaboration (ATRC) utilizes similar methods to RLS (above) which is a volunteer offshoot of the LTTRMP. The main difference is a standardized number of replicate transects at each site (4) and fixed depths, plus this method uses algal quadrats to record the full range of species present under points under quadrats at each site. All data are currently on a custom SQL database, that is now being transitioned to an IMOS portal designed to share all national UVC datasets, including RLS	Over 660 sites surveyed in temperate Australia, many surveyed multiple times as part of long-term monitoring of MPAs as they became established. Time series extend to 26 years in some locations.	http://atrc.org.au/

Name	Description	Species	URL
AIMS LTM	This program was initially established to monitor coral reef health in the GBR, particularly tracking changes associated with COTS outbreaks. The methods relate to that initial focus and include manta-tows for coral cover/health, and diver-based UVC transects for subsets of fishes and specific invertebrates such as COTS. As such the methods are well suited to monitoring COTS, the influence of COTS on corals, changes in target species abundance and size and emerging factors such as coral bleaching. As the full set of fishes in an assembly are not surveyed (due to complexity, time and training), the data are not fully compatible with RLS and LTTRMP data for all diversity metrics. Data are stored on a bespoke database developed by AIMS	226 sites over 26 years.	
ALA	The Atlas of Living Australia is a collaborative, national project that aggregates biodiversity data from multiple sources and makes it freely available and usable online. Sources include RLS and the LTTRMP above, in addition to most museum species location records	75 million records covering 122 thousand species from marine, freshwater and terrestrial ecosystems.	https://www.ala.org.au/
GBIF	Global Biodiversity Information Facility—is an international network and research infrastructure funded by the world's governments and aimed at providing anyone, anywhere, open access to data about all types of life on Earth. Sources include RLS above, in addition to sources feeding into ALA.	100 billion occurrence records, from 40 thousand datasets, covering 14 million species from marine, freshwater and terrestrial ecosystems.	https://www.gbif.org/
INaturalist	INaturalists use citizen scientists to log locations of observations. Each record is verified by specialist scientists.	Globally 11 million observations from 172 thousand species from marine, freshwater and terrestrial ecosystems.	https://www.inaturalist.org/

Name	Description	Species	URL
RedMap	The RedMap project is a relies on citizen scientists around Australian community to spot, log and map marine species that are uncommon in Australia, or along particular parts of our coast. Each record is verified by specialist scientists.		http://www.redmap.org.au/
BioTIME	BioTIME is an open access resource, free to anyone, anywhere in the world to use for education, research or conservation. BioTIME is a comprehensive collection of assemblage time-series in which the abundances of the species that comprise ecological communities have been monitored over a number of years. BioTIME data span the globe and encompass terrestrial, freshwater and marine ecosystems.	The current version of BioTIME contains over 12 million records, from 50 thousand species	http://biotime.st-andrews.ac.uk/
Seamap Australia	Seamap Australia is an open-access Australian seabed habitat classification scheme and spatial database. It is supported by, and embedded within, the AODN data infrastructure. It currently displays spatially mapped habitat layers from arrange of sources around Australia, primarily State agencies and State waters at this stage. It also has the ability to link to spatially related imagery such as from RLS photo-quadrats and the IMOS AUV photo-transects, and this capacity, plus the capacity to display a wider range of bathymetric maps, is evolving.	Habitats, Multibeam sonar	https://seamapaustralia.org/

Name	Description	Species	URL
AusSeaBed	AusSeabed is a national seabed mapping coordination program aiming to serve the Australian community relying on seabed data by coordinating collection efforts in Australian waters and improving data access. It is at an early stage of development, but the intent is to collate all multibeam sonar data (raw through to processed and gridded) and hold in the data cloud at Geosciences Australia. When fully developed it should allow access to data selected on a spatially constrained basis and support tools for data visualisation. This may include the ability to link to other spatially related visual products such as imagery from portals such as Global Archive and Squidle +, and derived habitat layers from platforms such as Seamap Australia above. AusSeaBed is currently hosted by the Geosciences Australia infrastructure and overseen by a national steering committee.	Multibeam sonar	http://www.ausseabed.gov.au/
AODN	The AODN Portal provides access to all available Australian marine and climate science data and provides the primary access to IMOS data	Species, Morphospecies, Habitats, Climate, Physical.	https://portal.aodn.org.au/

4. PROGRESS TOWARDS NATIONAL REPORTING AND INTEGRATED MONITORING OBJECTIVES

In the benthic environment, considerable progress has been made towards national-level monitoring and reporting of marine biodiversity values over recent years. Likewise, similar progress has been made with respect to collation, visualisation and sharing of mapping information necessary to underpin this biological understanding. Table 2 summarises key elements of this capability across the most commonly used platforms.

For the NNSC objective of “Systematic exploration mapping and characterisation of our marine estate and for monitoring the condition of key assets” there has been significant engagement with both the AusSeaBed and Seamap Australia initiatives to collect, collate and share mapping data. This engagement has been widely based, including both State and Commonwealth agencies and research institutions and has built on NESP Hub initiatives to collate current data and prioritise future mapping programs. With developments of SOPs for multibeam mapping, and AusSeaBed workshops to continue prioritisation of national mapping, there has been substantial progress towards improved national level coordination in this space. However, there is significant scope for further advancement, including prioritising MNF vessel time for surveying priority areas and developing an inshore MNF capability to more cost-effectively undertake shallow-water mapping programs.

Table 3. Overview of major sampling platforms currently in widespread use and the extent they are supported across institutions, by SOPs, national databases and have the capacity to report into SOE currently or in the near future.

Method	Major Datasets	Database	Target group	Habitat	Temporal data	Used in monitoring	Open data	National coverage	Use in monitoring publication	Use in SOE	Potential for next SOE
AUV	NESP/IMAS/ UWA/ NSW	Squidle+	Benthic cover	Reef/shelf	Yes	Monitoring	Yes	Yes	Yes, an example	Partial	Yes
BRUV	UWA/ Curtin/ AIMS/ NSW DPI	Global archive	Demersal fishes	Shelf habitats	Yes	monitoring	Yes/partial	Yes	Yes	Partial	Yes
Towed video	CSIRO/ AIMS/	Agency-potential for Squidle+	Benthic cover, habitat, demersal fishes, large mobile invertebrates	All habitats from coastal to abyssal	Limited	Limited primarily to AIMS	No	No	No	Partial	Partial-regional
UVC	ATRC/ AIMS LTMP/ RLS/Vic.	In development/ Agency	reef fishes, mobile invertebrates and sessile benthic cover	Shallow coastal reefs	Yes	Monitoring	Yes/partial	Yes	Yes	Yes	Yes
Sled /Grab	Museum/ MNF	No. Distributed data to ALA and xx	Benthic cover, infauna, demersal fishes, large mobile invertebrates	Shelf to abyssal	Limited	Limited	Partial	No	No	No	No
Trawl	NSW DPI/ CSIRO	No	Demersal fishes/prawns	Shelf to seamount	Limited	Limited	No	No	Yes	Yes	No
Acoustic tagging	IMOS partners	Yes	Mobile species	Coastal /shelf	Yes	Limited	Yes/partial	Partial	No	No	No

For the NMSC objective of “Bring together existing data sets held by governments, agencies, universities and industries” there has also been significant progress. In some cases this has been undertaken as a once-off synthesis for a particular reporting requirement (e.g. UVC data for SOE reporting, Stuart-Smith et al. 2017; AUV imagery for machine-learning training, Bewley et al 2015), but with support from agencies such as IMOS/AODN, this is increasingly being established on an ongoing basis as a series of national repositories of open access data. Significant infrastructure underpinning this access now supports key datasets from platforms including UVC, BRUVs, AUVs, acoustic monitoring of mobile/migratory organisms and marine seabed mapping. In addition to existing online data platforms such as the AODN and ALA, this data storage, sharing and discoverability has increased substantially over the past five years with the development of interactive web-portals for exploring and downloading fish (www.globalarchive.org and www.reeflifesurvey.com), habitat mapping (www.seamapaustralia.org), seabed biodiversity (squidle.org) and multibeam sonar (http://ausseabed.gov.au) datasets. However, despite this progress and increasing willingness of research providers to contribute and share data, some datasets remain uncollated. These currently include towed video and sled/grab samples, and to a certain extent many current AUV annotations. The need for these datasets to be collated has been identified, and progress is being made towards their implementation, particularly for annotated imagery as developments in infrastructure such as Squidle+ enable these to be readily added and curated.

Underpinning much of the engagement with evolving databases has been the establishment of national working groups (e.g. the NMSC national marine monitoring working group, national AUV benthic ecology steering committee, national BRUV working group) and the development of national SOPs (Przeslawski & Foster, 2018) to ensure continued consistency in data collection efforts across platforms.

For the NMSC objective “Establish methods and data standards for developing environmental baselines and long-term monitoring” there have been a number of significant developments over the past eight years, most notable the program undertaken by the NESP Marine Biodiversity Hub to work with the national science community to develop SOPs for a range of widely-used platforms. For all the monitoring methods described previously, SOPs have been developed and are in widespread use. There remain some challenges to be able to better integrate components of some existing long-term programs (e.g. the RLS/ATRC UVC methods with the AIMS LTMP methods used in the GBR), however, for the majority of tools there is increasing realisation of the value of an SOP-based approach to monitoring and the ability to fully integrate across programs and with emerging national databases. This is being further reinforced by database structures, such as Global Archive and Squidle+ that encourage data input in set formats.

For the NMSC objective “Provide a basis for reporting the state of the national marine environment and impact of cumulative pressure on high value systems” there has also been significant progress on several fronts, including those discussed above. The establishment of agreed SOPs and national database infrastructure has facilitated the basis for being able to report at a national level across multiple platforms, including UVC, BRUVs and AUVs. As an example, state of environment reporting metrics has been developed for fishes based on UVC datasets (Stuart-Smith et al. 2016) and these are currently being adapted for fishes based on BRUV datasets (Monk et al. 2018). In both cases, sufficient monitoring data now exists to begin regular contributions to SOE reporting at national scales and at time-frames applicable to the usual five-year cycle of reporting.

Similarly, Bewley et al. (2015) provided a synthesis of annotated AUV imagery collated in the Squidle database but no attempt was made at that stage to recommend suitable metrics for national level reporting. However, this data was used by Marzinelli et al. (2015) to make the first quantitative estimate of kelp cover at national scale, providing a case study on the reporting capability of this program, and an example of a valuable reporting metric that could be readily monitored at SOE reporting time-scales as part of the IMOS supported national AUV program. At this stage, the Bewley et al. 2015 synthesis is now dated, and there is no nationally agreed functional database for storing annotations, nor coordinated active scoring of acquired imagery by key agencies involved in the AUV program. Developments with Squidle+ should see this overcome in the next year as part of the proposed UMI facility. The UMI development includes establishment of a national morphospecies (OTU) image-library, to allow all datasets to match-back to agreed including taxonomic units, facilitating future SOE reporting at multiple levels, from biodiversity trends through to changes in overall canopy cover or cover of key species. One additional feature of the proposed UMI platform is that it is also being configured to facilitate future automation of the annotation process for core reporting metrics such as algal or coral cover, removing much of the time-consuming manual annotation needed currently. Significant experimental development has already been undertaken in the automation field, with good progress being made by UWA towards automation of kelp cover, and similar progress being made by AIMS for cover of coral and coral forms. A current ARC-Linkage application for an image-analysis automation facility, if funded, would facilitate coordination of national efforts in this space across agencies and provide a quality-controlled expert annotated dataset from which to develop and trial automation methods that are advancing rapidly globally.

Certainly, for many other potential monitoring methods, progress is at a slower state. For example, considerable effort is required to collate annotations from towed video platforms around Australia although this method is likely to hold some of the largest (spatial and temporal) coverage datasets in Australia. The lack of consistency in annotations between many researchers and agencies currently limits the biological resolution, and thus the geographical coverage and range, of metrics for national level reporting. Despite this, the process of collating the available data is a valuable step, likely leading to the discovery and archiving of much historical imagery that would otherwise be lost. Likewise, the advancement of SOPs will likely advance the standardisation of towed-video approaches in national programs, and developments of applicable database tools such as Squidle+ and UMI will further facilitate this progress.

Some platforms, such as Grab/Sled/Trawl currently lack the infrastructure necessary to collate and report data at a national scale in a way suitable for monitoring, and in many cases programs have not been designed with monitoring in mind, and hence have not followed any particular standard protocol. With the development of SOPs for many of these methods, an opportunity exists to develop a national database that captures existing datasets and is part of or integrates with current database initiatives such as UMI/Squidle+ and the national reef monitoring database (UVC).

Similarly, animal tracking datasets have value in long-term monitoring and may reveal changes in migration patterns which may be a useful national-level reporting metric (e.g. Brodie et al. 2018), in addition to supporting population estimates of migratory species via CMR. However, while much of the raw data from the IMOS acoustic tracking network is databased, additional work is required for developing, refining and trialling national-level metrics, as well as summarising much of the raw data into meaningful outputs for assessment.

5. RECOMMENDATIONS

Key points of this review are covered in the Executive Summary. However, noting that very significant progress has been made over the past eight years in bringing the national scientific and management community together to develop nationally integrated approached to monitoring and reporting, there are a number of recommendations that could support continuing advancement.

These include:

Databases: Ongoing support for development of national databases and reporting tools, and in-built flexibility to incorporate a range of monitoring platforms in database tools where appropriate to better integrate platforms into the national data infrastructure (e.g., capability to incorporate ROV and Towed video datasets into tools such as Squidle+ or Global Archive).

Data Access and Reporting: Establish quality standards or FAIRness measures for national monitoring data infrastructure, including nationally and internationally agreed reporting metrics. FAIRness measures could help address issues about data access whereas a quality framework could more broadly address quality of science, products, services, and stewardship.

Standard practices: Encouragement of uptake of SOPs wherever possible, including industry and consultancies, with data provided to national data repositories as open access wherever possible. Ideally this encouragement would apply to all major surveys, including environmental assessments undertaken in response to regulatory requirements. Parks Australia has started requiring researchers to follow SOPs, including data requirements, through their national Marine Science Program, providing leadership in this space.

Governance: Maintain and support existing working groups around major monitoring platforms and encourage similar groups to advance the use of other platforms in an integrated monitoring framework (e.g., Towed-Video and ROVs).

Infrastructure Support: Improve access to the MNF facility, particularly through support of a ***national coastal research vessel fleet*** to support and address national monitoring programs and associated priority mapping needs on a cost-effective basis. The lack of appropriate vessels and funding access is an ongoing and yet to be addressed issue that is significantly limiting our current ability to undertake tasks such as shelf-based mapping and deployment of the IMOS AUV facility, particularly with respect to meeting future AMP inventory and monitoring needs.

REFERENCES

Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G. 1997. Changes after twenty years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. NSW Fisheries Final Report Series No. 1 FRDC Project No. 96/139

Arnould, John P. Y., Jacquomo Monk, Daniel Ierodiaconou, Mark A. Hindell, Jayson Semmens, Andrew J. Hoskins, Daniel P. Costa, Kyler Abernathy, and Greg J. Marshall. 2015. “Use of Anthropogenic Sea Floor Structures by Australian Fur Seals: Potential Positive Ecological Impacts of Marine Industrial Development?” *PloS One* 10 (7): e0130581.

Bewley, Michael, Ariell Friedman, Renata Ferrari, Nicole Hill, Renae Hovey, Neville Barrett, Ezequiel M. Marzinelli, et al. 2015. “Australian Sea-Floor Survey Data, with Images and Expert Annotations.” *Scientific Data* 2 (October): 150057.

Brodie, Stephanie, Elodie J. I. Lédée, Michelle R. Heupel, Russell C. Babcock, Hamish A. Campbell, Daniel C. Gledhill, Xavier Hoenner, et al. 2018. “Continental-Scale Animal Tracking Reveals Functional Movement Classes across Marine Taxa.” *Scientific Reports* 8 (1): 3717.

Butchart, Stuart H. M., Matt Walpole, Ben Collen, Arco van Strien, Jörn P. W. Scharlemann, Rosamunde E. A. Almond, Jonathan E. M. Baillie, et al. 2010. “Global Biodiversity: Indicators of Recent Declines.” *Science* 328 (5982): 1164–68.

Carroll A, Althaus F, Beaman R, Friedman A, Ierodiaconou D, Ingleton T, Jordan A, Linklater M, Monk J, Post A, Przeslawski R, Smith J, Stowar M, Tran M, Tyndall A. 2020. Marine sampling field manual for towed underwater camera systems. In *Field Manuals for Marine Sampling to Monitor Australian Waters*, *Version* 2. Przeslawski R, Foster S (Eds). National Environmental Science Programme (NESP). https://towed-imagery-field-manual.github.io/

Dornelas, Maria, Laura H. Antão, Faye Moyes, Amanda E. Bates, Anne E. Magurran, Dušan Adam, Asem A. Akhmetzhanova, et al. 2018. “BioTIME: A Database of Biodiversity Time Series for the Anthropocene.” *Global Ecology and Biogeography: A Journal of Macroecology* 27 (7): 760–86.

Harvey, Euan S., Dianne L. McLean, Jordan S. Goetze, Benjamin J. Saunders, Tim J. Langlois, Jacquomo Monk, Neville Barrett, et al. 2021. “The BRUVs Workshop – An Australia-Wide Synthesis of Baited Remote Underwater Video Data to Answer Broad-Scale Ecological Questions about Fish, Sharks and Rays.” *Marine Policy* 127 (May): 104430.

Hays, Graeme C., Anthony J. Richardson, and Carol Robinson. 2005. “Climate Change and Marine Plankton.” *Trends in Ecology & Evolution* 20 (6): 337–44.

Hinder, Stephanie L., Graeme C. Hays, Martin Edwards, Emily C. Roberts, Anthony W. Walne, and Mike B. Gravenor. 2012. “Changes in Marine Dinoflagellate and Diatom Abundance under Climate Change.” *Nature Climate Change* 2 (4): 271–75.

Hoenner, Xavier, Charlie Huveneers, Andre Steckenreuter, Colin Simpfendorfer, Katherine Tattersall, Fabrice Jaine, Natalia Atkins, et al. 2018. “Australia’s Continental-Scale Acoustic Tracking Database and Its Automated Quality Control Process.” *Scientific Data* 5 (January): 170206.

James LC, Marzloff MP, Barrett N, Friedman A, Johnson CR (2017). Changes in deep reef benthic community composition across a latitudinal and environmental gradient in temperate Eastern Australia. Mar Ecol Prog Ser 565:35-52. https://doi.org/10.3354/meps11989

Marzinelli, E., Williams, S., Babcock, R., Barrett, N., Johnson, C., Jordan, A., Kendrick, G., Pizarro, O., Smale, D., Steinberg. P. (2015). Large-Scale Geographic Variation in Distribution and Abundance of Australian Deep-Water Kelp Forests. *Plos One* https://doi.org/10.1371/journal.pone.0118390

Monk J, Barrett N, Bridge T, Carroll A, Friedman A, Ierodiaconou D, Jordan A, Kendrick G, Lucieer V. 2018. Marine sampling field manual for autonomous underwater vehicles (AUVs). In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 2. Przeslawski R, Foster S (Eds). National Environmental Science Program (NESP).

Pereira, H. M., S. Ferrier, M. Walters, G. N. Geller, R. H. G. Jongman, R. J. Scholes, M. W. Bruford, et al. 2013. “Ecology. Essential Biodiversity Variables.” *Science* 339 (6117): 277–78.

Pereira, Henrique Miguel, Laetitia Marie Navarro, and Inês Santos Martins. 2012. “Global Biodiversity Change: The Bad, the Good, and the Unknown.” *Annual Review of Environment and Resources* 37 (1): 25–50.

Perkins, N. Monk, J. Barrett, N. (2021) Analysis of a time-series of benthic imagery from the South-east Marine Parks Network. Report to Parks Australia. https://parksaustralia.gov.au/marine/pub/MPA-SE-AUV-Analysis-Final-Report.pdf

Przeslawski R., S. Foster [Eds.] 2018. Field Manuals for Marine Sampling to Monitor Australian Waters, Version 1. 2018. Report to the National Environmental Science Programme, Marine Biodiversity Hub. 212 pp. http://dx.doi.org/10.11636/9781925297669

Ross, A., and MacLeod, C. (2017). Environmental research in Macquarie Harbour: interim synopsis of benthic and water column conditions. IMAS report to the Environmental Protection Authority and Department of Primary Industries, Parks, Water and Environment Tasmania. http://epa.tas.gov.au/Documents/IMAS%20Technical%20Report%20on%20Macquarie%20Harbour%20Condition.pdf

Stuart-Smith, R., Edgar, G., Barrett, N., Bates, A. et al. (2017). Assessing National Biodiversity Trends for Rocky and Coral Reefs through the Integration of Citizen Science and Scientific Monitoring Programs. *BioScience,* 67:134–146, https://doi.org/10.1093/biosci/biw180

Sweatman, H., Delean, S. & Syms, C. (2011). Assessing loss of coral cover on Australia’s Great Barrier Reef over two decades, with implications for longer-term trends *Coral Reefs* 30: 521. https://doi.org/10.1007/s00338-010-0715-1

Williams, A., Althaus, F, and Schlacher, T. (2015). Towed camera imagery and benthic sled catches provide different views of seamount benthic diversity*. Limnology and Oceanography Methods* 13: 62-73 **https://doi.org/10.1002/lom3.10007**

Zintzen, Vincent, Marti J. Anderson, Clive D. Roberts, Euan S. Harvey, Andrew L. Stewart, and Carl D. Struthers. 2012. “Diversity and Composition of Demersal Fishes along a Depth Gradient Assessed by Baited Remote Underwater Stereo-Video.” *PloS One* 7 (10): e48522.

www.nespmarine.edu.au

Contacts:

Dr Jacquomo Monk
Institute for Marine and Antarctic Studies,
University of Tasmania.

Address | Private Bag 49, HOBART, TAS, 7001
emails | jacquomo.monk@utas.edu.au
tel | +61 6226 8385

Assoc. Prof Neville Barrett
Institute for Marine and Antarctic Studies,
University of Tasmania.

Address | Private Bag 49, HOBART, TAS, 7001
emails | neville.barrett@utas.edu.au
tel | +61 6226 8210