Marine Biodiversity Hub

National Environmental Science Programme

Scoping of new field manuals for marine sampling in Australian waters

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Project D2: Standard operating procedures for survey design, condition assessment and trend detection

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Important Disclaimer

Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

A suite of field manuals was released by the NESP Marine Hub in early 2018 to facilitate a national monitoring framework, with a focus on seven marine sampling platforms: multibeam sonar, autonomous underwater vehicles, baited remote underwater video (pelagic and demersal), towed imagery, sleds and trawls, and grabs and box corers. These platforms were identified based on frequency of use in previous open water sampling and monitoring programs. Stakeholder feedback revealed several key sampling platforms and data types not included in the original release, as well as a possible need for field manuals related to cultural or socioeconomic standard operating procedures (SOPs).

The current report scopes the need and feasibility of developing new field manuals as related to monitoring Australia's waters for the following:

- Remote operating vehicles (ROVs)
- Passive acoustic monitoring (PAM)
- Sub-bottom profiling (SBP)
- Drones
- Satellite imagery
- Marine plastics
- Environmental DNA (e-DNA)
- Plankton
- Sampling for Sea Country
- Socioeconomic monitoring

Based on recommendations provided here, an ROV field manual seems necessary and achievable for the NESP Marine Hub program in 2019-2020, while the new NESP Project D6 will provide foundations in 2019-2020 from which a new SOP on socioeconomic monitoring may eventuate. A further six SOPs and associated field manuals may be developed in the future (UVC, PAM, SBP, drones, e-DNA, plankton), assuming suitable resources are secured, including a champion to chair a collaborative working group and lead the development of a field manual.

Recommendations from this report indicate that three of the scoped SOPs are not needed, either due to a scope too broad to allow a national SOP (satellite imagery) or other initiatives that are already in advanced development stages (marine plastics, sampling for Sea Country).

1. INTRODUCTION

In early 2018, *Field Manuals for Marine Sampling to Monitor Australian Waters, Version 1* was released (Przeslawski and Foster 2018). This suite of field manuals aims to provide a standardised national methodology for the acquisition of marine data from a prioritised set of frequently-used sampling platforms (below diver depth) so that data are directly comparable in time and through space. The field manuals for this first version focus on standard operating procedures (SOPs) for seven marine sampling platforms. These platforms were identified based on frequency of use in previous open water sampling and monitoring programs:

- multibeam sonar,
- autonomous underwater vehicles,
- demersal baited remote underwater video,
- pelagic baited remote underwater video,
- towed imagery,
- sleds and trawls, and
- grabs and box corers.

After the release of the field manuals, feedback was sought from potential users and other stakeholders via meetings, emails, and an online questionnaire. The main purpose of the feedback was to inform Version 2 of the field manuals, to be released in 2019. However, responses also revealed several key sampling platforms and targets not included in the original release, as well as a possible need for field manuals related to cultural or socioeconomic best practices.

Notably, there was interest in developing national best practices for Indigenous engagement and Sea Country sampling. The former is excluded from this report, as we deemed it unsuitable to develop anything other than a very general national guidelines because Indigenous engagement for scientific research must be flexible enough to accommodate various regions, communities, and cultures. Sea Country sampling, however, is included in this report due to the potential links between the existing SOPs and Indigenous SOPs to meet the needs of both western science institutions (who want comparable and collatable national datasets) and Indigenous communities (who may seek to monitor cultural values in their Sea Country or Indigenous Protected Areas) (Jackson et al. 2015).

The current report scopes the need and feasibility of developing new field manuals. Importantly, this activity *will not develop new SOPs*, but rather *assess the need and resources required for such development* as they may relate to the current suite of NESP field manuals (www.nespmarine.edu.au/field-manuals).

Table 1 lists the potential SOPs to be scoped based on consultation and feedback with NESP researchers, field manual collaborators, and stakeholders. In addition, it is informed by the availability and willingness of experts to scope particular SOPs and potentially lead associated field manuals in the future. The former point is important to note, as it means that *the inclusion or exclusion of a given platform in this report may simply be due to the availability of experts to contribute*. Whenever possible, this report will point to existing groups or programs that are leading or may lead the development of future SOPs or field manuals. By nature of the institutional support behind this report, such programs will inevitably focus on the NESP Marine Biodiversity Hub and its partner organisations, but we have also tried to expand from this when possible.

Table 1 Key sampling platforms and targets scoped for new field manuals. The co-authors listed are those that would become or identify champions for the relevant field manual, if applicable.

Potential New Field Manual	Scoping report co-author
Sampling Platforms	
Underwater Visual Census (UVC)	Rick Stuart-Smith, Alistair Cheal
ROV	Jacquomo Monk
Passive acoustics	Andrew Carroll
Sub-bottom profiling	Scott Nichol
Drones	Aero Lepastrier
Satellite Imagery	Inke Falkner, Stephen Sagar
Sampling Target	
Marine plastics	Britta Denise Hardesty
e-DNA	Lev Bodrossy, Jodie van de Kamp
Plankton	Joel Williams
Cultural	
Sampling for Sea Country	Karen Miller, Martial Depczynski, Paul Hedge
Socioeconomic	
Socioeconomic monitoring	Tim Langlois

For each of the topics listed in Table 1, the following issues are addressed wherever possible:

- Established methods, including current SOPs.
- Relationship to marine monitoring
- Update needs (i.e. how often will the manual need updating?)
- Likelihood of forming a functional working group to develop content
- Potential scope of SOP
- Assessment of the need for a new SOP and recommendation

2. SAMPLING PLATFORMS

2.1 Underwater Visual Census (UVCs)

Underwater visual census (UVC) encompass a range of methods used to characterise and detect changes in ecological assemblages in shallow water habitats, including coral and temperate rocky reefs. UVC can be done solely using *in situ* observations by scuba divers or snorkelers, or it can be combined with acquired imagery.

Existing SOPs & applications to marine monitoring

In Australia, there are a number of monitoring programs that employ UVC, but the three largest scale programs, which have existing SOPs are:

- Reef Life Survey (RLS) is a global citizen science program established in Australia in 2007, with widely applied methods (used in 54 countries around the world). The RLS field manual is available at http://reeflisfesurvey.com/reef-life-survey/about-rls/methods and is listed on the Ocean Best Practise repository. The SOPs from RLS are similar to, and were based on the methods used in the ATRC (below).
- The Australian Temperate Reef Collaboration (ATRC; formerly the long-term temperate MPA monitoring program; http://atrc.org.au/) is a continent-wide program operated from the University of Tasmania since 1991. Its SOPs are applied for the purpose of monitoring MPAs in temperate Australia in collaboration with state management agency partners.
- The Australian Institute of Marine Science (AIMS) Long-Term Monitoring Program (LTMP) is the longest running UVC program in Australia and has been in operation since the early 1980s. The LTMP uses multiple methods focused on different groups of organisms (e.g. crown-of-thorns starfish, benthic assemblages and reef fishes). Each of these methodologies have their own detailed SOP, initially developed for the GBR, but the SOPs have also been applied on reefs in north-west Australia for decades (www.aims.gov.au/docs/research/monitoring/reef/sops.html).

There are also state UVC programs, but the SOPs are either aligned with the programs above, or not widely applied outside of the state or territory program. Notably, the Victorian Government Subtidal Reef Monitoring Program has used the same methods as ATRC. There is also an ongoing UVC program through James Cook University that has monitored coral and fish communities on inshore reefs of the GBR since 1998 to assess management zoning, using similar methods to the AIMS LTMP. Representatives from all of these programs should be invited to contribute to any national field manual.

The programs mentioned above are used not only to determine ecological status and trends, but also for MPA monitoring. Data are used for a variety of purposes including performance and management plans, evaluations and reviews, and research and public outreach. RLS is also designed to link into State of Environment reporting. AIMS LTMP contributes to the GBR Outlook Report and directly informs managers of the GBR and government agencies. The LTMP may soon be incorporated into the GBR Reef Integrated Monitoring and Reporting Program (RIMReP).

Updates

Since the methods of UVC should be kept consistent through the long-term and do not rely on changing field technology, SOPs would only need to be updated when digital infrastructure and workflows related to marine imagery or other collected data develop and change.

Working group

Formation of a new working group is unlikely without additional resources, as key contributors have already developed their own SOPs for their programs (e.g. RLS, AIMS LTMP, Australian Temperate Reef Collaboration). If resources become available and a champion identified, information in existing SOPs could be assessed and compiled into a single, broadly applicable UVC SOP that has agreed minimum components.

Potential scope of SOP

The largest UVC programs focus on similar target organisms, and much of the background information, basic methods and issues to be aware of are generic. These “common ground” aspects could be adapted into a new field manual that outlines best practise principles of UVC that when applied allow comparison of data with a range of past and ongoing programs. Any SOP put forward as the national standard should integrate aspects of the existing long-term programs in Australia to increase capacity for data synthesis and analysis.

An alternative to a single SOP is the development of a ‘rosetta stone’ that links the data from each method. This approach would also require additional resources due to the complex analyses that would be required.

Assessment and recommendation

Despite some generic similarities, there are key differences among existing methods (e.g. inclusion and timing of video quadrats, (Emslie et al. 2018)). These will need to be discussed by the key users of the methods to reach a compromise that meets each program’s needs while still addressing the overall need to national consistency or comparability of data.

There is no need to generate a new SOP from scratch, as the benefits of the long-time series or extensive spatial comparability amongst all these programs using UVC would be lost if the methods were to be changed. Instead, we recommend that if resources are identified, the differences between the three major UVC programs are reviewed and a standard approach is developed to integrate data from these methods (i.e. quantify systematic biases and develop correction factors). In the interim, we recommend that any new UVCs being undertaken should abide by SOPs developed by RLS, AIMS or LMTP.

2.2 Remote Operating Vehicles (ROVs)

Remotely operate vehicles (ROVs) are arguably among the least evaluated of the deep-water monitoring platforms, yet have a number of strengths that could make them important tools in the future (Karpov et al. 2012, Rosen and Lauermann 2016) (Karpov et al. 2012, Lauermann 2014). Depending on their task, ROVs vary in shape, size, depth rating and payload capability. ROVs enable the precise collection of physical and observational (using acoustic and optical) samples from the water column and seafloor (Linley et al. 2013, Macreadie et al. 2018). Although manned submersibles exist that can transport humans to similar extreme depths, ROVs are a more compact, portable and practical alternative, without the human risk element. An ROV can be manoeuvred precisely with its thrusters. Scientists can see the undisturbed area from where samples are selectively taken, providing them with a better understanding of habitats and structures. Complex in situ experiments can also be achieved maintaining the environmental conditions and minimising sample damage caused by recovery to the surface.

Existing SOPS & applications to marine monitoring

Australia currently has no national SOPs for ROVs in marine monitoring. However, other parts of the world have developed at least four existing standard operating procedures for ROVs (Christ and Wernli Sr 2013, Horn and White 2014, IMCA 2014, JNCC 2018).

While the use of ROVs in Australia for monitoring marine biodiversity is relatively untested, ROVs are particularly well-suited to the fine-scale quantitative estimation of benthic floral and faunal cover, especially in rugged habitat, as well as selected benthic fishes, epi-benthic fishes, and ground-truthing of major habitat features (Quattrini et al. 2017).

Updates

An SOP would not be wedded to a particular model of ROV, thus meaning updates would be needed only when the digital infrastructure or workflow to support acquired marine imagery develops or changes.

Working group

With the rigs-to-reefs movement (e.g. Macreadie, McLean et al. 2018) and the introduction of cheap ROVs (e.g. BlueROVs; https://www.bluerobotics.com/) there is increased interest in the use of ROVs within Australia. Accordingly, a working group should not be particularly difficult for establish.

Potential scope of SOP

The potential scope for a new SOP for Australia will likely be centred around the sampling of the epibenthos using acoustic (e.g. Huvenne et al. 2011) or visual imagery (e.g. Macreadie et al. 2018). However, physical and chemical sampling of the benthos and water column is also possible from ROVs and could be included in the SOP, especially as it may interfere with standard transect survey operations. The SOP should include the issue of adaptive sampling and associated survey design which is likely to be challenging when applied to ROVs.

Assessment and recommendation

ROVs are being increasingly applied to marine monitoring in Australian waters, but there is as yet no national SOP to guide these activities to ensure nationally consistent data. We recommend that a comprehensive assessment of current ROV use in Australia be undertaken to ensure interests are best be represented in a nationally collaborative manner. There is already a core group of Australian researchers willing and able to form a working group, and they can expand this working group using results from this assessment. Since the need, interest, and capability are there, we recommend a new ROV field manual developed in 2019-2020 as part of the NESP Marine Biodiversity Hub's suite of field manuals.

2.3 Passive Acoustics

Passive Acoustic Monitoring (PAM) is an increasingly used method to augment standard visual monitoring methods for the detection and classification of fish and vocalising marine mammals (Cato et al. 2006, Soldevilla et al. 2014), as well as abiotic noise (e.g. waves, rainfall). PAM can use a fixed or towed hydrophone array to detect the presence of whales and other acoustically active cetaceans e.g. sperm whales in (Thode 2004) and estimate their location relative to the hydrophone array. Marine mammal species are identified by the specific temporal and spectral characteristics of their vocalizations (Figure 1). Passive acoustic hydrophones can also be mounted on mobile platforms such as gliders and Argo floats.

Existing SOPS & applications to marine monitoring

While the technique is inherently limited to animals that produce sound, PAM has become a fundamental tool, not only for researching the behaviour of whales, but for designing real-time mitigation protocols that may minimise the potential impacts of anthropogenic activities such as marine seismic surveys and ship-strikes on whales (Nowacek et al. 2013, Soldevilla et al. 2014) . PAM is particularly useful for detecting whales that are unsuited to visual detection due to time spent at depth, low profiles, or inconspicuous behaviour at the surface e.g. beaked whales in (Yack et al. 2013). It is also increasingly considered by regulators as an appropriate tool for conducting marine mammal monitoring during poor visibility conditions (i.e. during night time operations, high sea state or fog).

However, with the exception of guidance provided by the International Association of Geophysical Contractors, there are currently no domestic or international standards relating to the measurement, data analysis and reporting for passive acoustic monitoring. Consequently, the quality of many environmental impact assessments is poor and data are not comparable (Erbe 2013a) (Erbe 2013b). Although PAM is increasingly considered a qualified tool for conducting marine mammal monitoring the performance of commercially available PAM systems is highly variable.

Updates

The manual would need to be evaluated for updating every 2-3 years, as technology to acquire and interpret acoustic signals is rapidly advancing. In addition, the protocols for data accessibility and discoverability will likely need to be revisited as data infrastructure capability and capacity grows to accommodate larger datasets such as those generated by PAM.

Working group

A working group to develop a PAM field manual would require resources such that a lead author could coordinate key acousticians, technicians, cetacean biologists, and ecologists to reach consensus about SOPs for PAM in Australia. Key researchers on noise impacts at Curtin University would be crucial, as well as at least one representative from international initiatives (e.g. Quiet Ocean project). One of the Essential Ocean Variables developed by GOOS is ocean sound, and the working group should therefore link into the EOVs as needed. In addition, due to previous history with acoustic monitoring through IMOS, it would be worth including them.

Potential scope of SOP

The objectives of a field manual should be to:

- Describe the minimum performance criteria for PAM;
- Specify technical and operational requirements and considerations; and,
- Describe pre-survey planning preparations, field implementation and post-survey procedures.

This would maximise the performance of PAM systems during geophysical and bioacoustic baseline and monitoring surveys.

In addition the SOP should describe the different types of hydrophones used as well as their appropriate calibration and deployment. This will ensure that acquired data is comparable among different gear, environments, and times.

Assessment and recommendation

A PAM SOP is feasible and practical to develop. It will provide guidance to enable the geophysical industry and bioacoustic research community to comply with monitoring and mitigation measures stipulated by regulatory agencies and emerging national standards. The primary aim of the field manual would be to establish a consistent approach to PAM in order to facilitate statistically sound comparisons between studies.

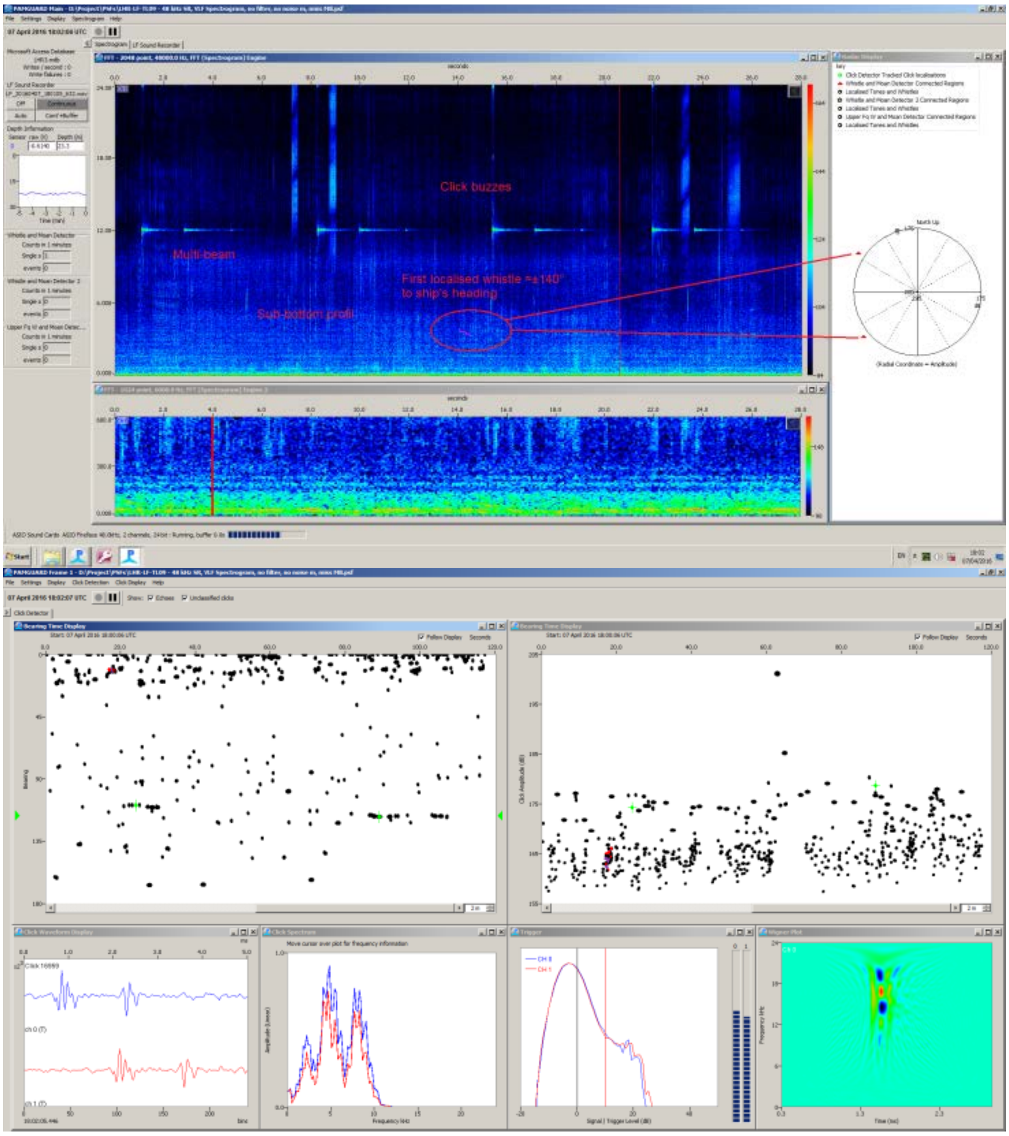

Figure 1 Acoustic detection of an unidentified pilot whale (*Globicephala* sp.) on the Lord Howe Rise visualised with PAMGuard.

2.4 Sub-Bottom Profiling

Sub-Bottom Profiling (SBP) is used to image and characterise the internal geological structure of seabed features to depths of tens to hundreds of metres below the sea floor. The technology has been widely adopted in marine geoscience because of the ability to collect data rapidly and non-destructively. The vertical resolution of a sub-bottom profile can range from decimetre for shallow (<100 m) studies to ~2m for deeper investigations.

Sub-bottom profilers are comprised of either a single or multiple channel acoustic source towed behind a vessel that sends energy pulses into the sub-sea floor strata. The sound pulses reflect off the sea floor and buried sedimentary layers according to differences in their acoustic impedance. Acoustic impedance is related to the density of the material and the rate at which sound travels through this material. The time taken for this signal to be returned and recorded by the sub-bottom profiler is used to calculate the depth of various strata and other features (e.g. fluids, gas) below the sea floor. In this way, a continuous image is provided along a survey line in 2-dimensions (Figure 2). Multiple survey lines can in turn be used to build a 3-D image of the sub seabed structure.

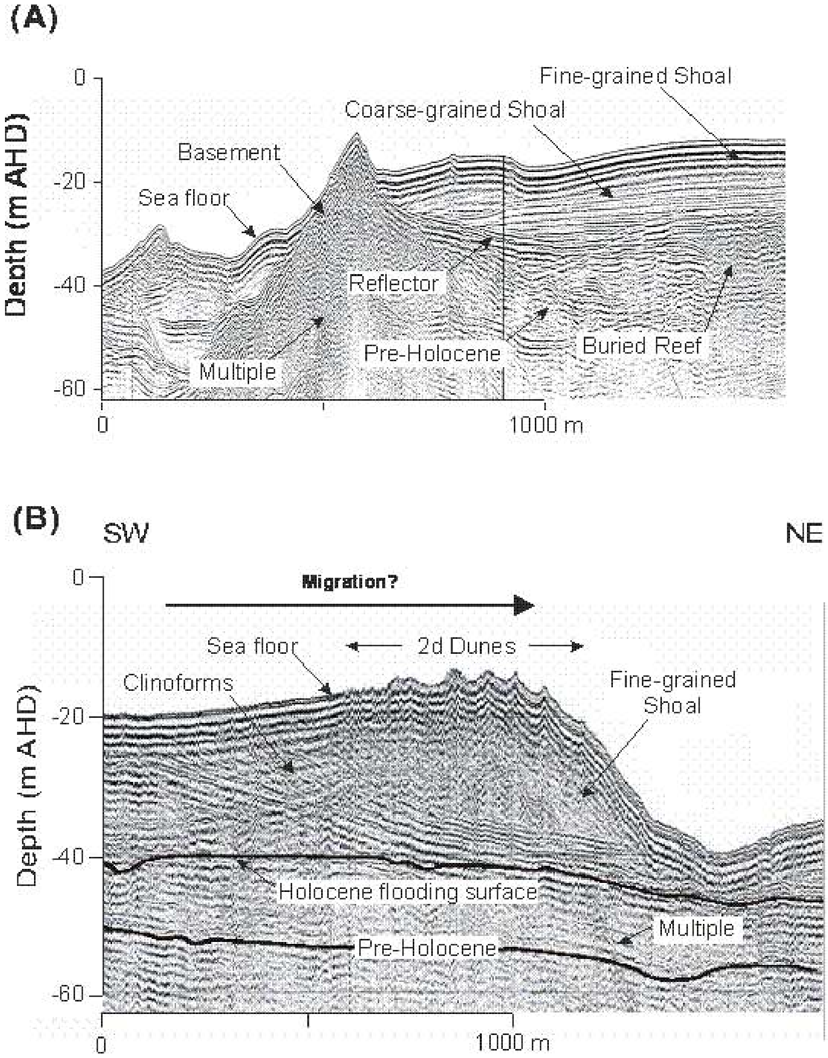

Figure 2 Boomer sub-bottom profiles of the sea floor around the Whitsunday Islands, Great Barrier Reef platform, Australia (after Heap 2000). (A) The reflectors reveal a range of recent, Holocene, and pre-Holocene features, showing an exposure of bedrock surround

There are a number of shallow SBP systems which operate using various types of sound sources and frequencies, as listed in Table 1. The particular SBP system used will depend on the objectives of the survey, water depths and prior knowledge of the local geology.

Table 1. Specifications of common SBP systems.

Sub-bottom profiler system	Frequency Range	Penetration depth and resolution
Parametric	~100 kHz	< 100 m, vertical resolution < 0.05 m
'Chirper'	3 to 40 kHz	< 100 m, vertical resolution ~0.05 m
'Pinger'	3.5 to 7 kHz	10 m to 50 m, with vertical resolution of 0.2 m
'Boomer'	500 Hz to 5 kHz	30 to 100 m, with vertical resolution of 0.3 to 1 m
'Sparker'	50 Hz to 4 kHz	To 1,000 m in ideal conditions, with vertical resolution of >2 m

Existing SOPS & applications to marine monitoring

Sub-bottom profiles do not provide a direct indication of seafloor biodiversity, similar to backscatter and bathymetry which have already been covered in *Field Manuals for Marine Sampling in Australian Waters* (Lucieer et al. 2018). They are, however, a key component of seabed mapping and the study of benthic habitats because they provide the geological context for physical features on the seabed (Caress et al. 2008, Harris and Heap 2009). As such, they contribute to the fundamental baseline information on seabed geomorphology, specifically the three-dimensional structure of geomorphic features (Crutchley and Kopp 2018, Moore et al. 2018). SBP data is also valuable for correlating with acoustic backscatter data (from multibeam sonar mapping of the seabed) to provide insights into sub-seabed structure, such as across hardground reefs and adjacent soft sediment areas (Nichol et al. 2013, Picard et al. 2018). For monitoring, SBP surveys can be used to determine the potential for change to seabed features that may occur in response to geological or oceanographic processes. Repeat SBP surveys would be used to detect and document any such changes. Examples of the application of SBP mapping to support monitoring include mapping the thickness of sedimentary deposits over bedrock in areas of active sediment transport, mapping the internal structure of active bedform fields to determine directions of transport (Beaman and Harris 2007), assessing the stability of seabed features across steep submarine terrains (e.g. within submarine canyons; (Gardner and Struthers 2013) and detecting the migration of gas or fluids to seabed features such as pockmarks (e.g. (Rise et al. 2015). All of these example applications (among others) relate directly to seabed habitats, with SBP profiling adding to the understanding of their spatial structure and temporal variability.

Updates

Once documented, SBP standards would need updating at a frequency of approximately 5+ years.

Working Group

Rather than create a new working group, a working group for developing an SOP for sub-bottom profile acquisition can be drawn from the existing AusSeabed community, as coordinated by Geoscience Australia. Key partners would potentially include representatives from the CSIRO Marine National Facility, offshore industry and university research sectors. Access to the SOP could also be provided via the AusSeabed web site (www.ausseabed.gov.au).

Potential scope of SOP

While SBP instruments are supported by system-specific operational guidelines provided by manufacturers, there are no standard guidelines for SBP acquisition for monitoring. A SOP would therefore be focused on aspects of survey design to ensure that robust and informative geoscientific data is collected. This would incorporate key concepts in line planning so as to capture geological structures along depositional strike and dip, and acquiring data across a grid to generate three-dimensional images of sub seabed structure. Linking SBP surveys to sample collection could also be incorporated by providing guidelines for site selection for sediment grabs, rock dredges and sediment cores. A SOP would also specify standards for data management, including file naming conventions, file formats and associated metadata.

Assessment and recommendation

There is a medium- to high-priority need for an SOP on sub-bottom profilers (i.e. within one to two years), and this could be managed through the AusSeabed program.

2.5 Drones

Unmanned aerial vehicles (or drones) are payload carrying, ground-based aircraft platforms that are most commonly user-controlled and come in a range of forms and sizes suited to different applications (Floreano and Wood 2015, Joyce et al. 2018). A variety of reasonably-priced drones are now accessible to industry, researchers, and the general public.

Existing SOPS & applications to marine monitoring

Drone-based observations fill the gap between satellite/manned-aircraft remote sensing and ground-based observations. The use of drones in the marine sphere has been growing exponentially as payload capacity, range, and flight-time increase concurrently with the miniaturisation and adaption of sensors to drone systems. A number of ecological and environmental monitoring studies have been published that demonstrate the cost-effectiveness of drones as a rapid and versatile spatio-temporal monitoring platform in preference to other traditional techniques (for summary of the benefits of drones over traditional aerial surveys (see Hodgson et al. 2013). In relation to marine monitoring, drones have been used for two-dimension habitat mapping (Joyce et al. 2018), detecting change (Ruwaimana et al. 2018), three-dimensional habitat complexity models, sea surface temperature (SST) observations (Casella et al. 2017), animal physiological and ecological monitoring of megafauna (Hodgson et al. 2013, Christiansen et al. 2018), and geomorphological modelling and coastal change detection (Ierodiaconou et al. 2016).

Marine drone-based studies have, to-date, mostly focused on the feasibility and the applications of these monitoring platforms. Work by Joyce et al. (2018) identifies the traps for new players associated with building an organisational drone capacity and the technical considerations necessary for successful flight operation. This information and advice would form a good introduction or operation section for a set of SOPs but ultimately the focus should be on specific details and principles of best practice to carry out the aforementioned monitoring activities. Gonzales and Johnson (2017) have developed a set of SOPs about surveying wildlife using drones, but this lacks detail about the different techniques available, use of different sensors, and consideration of marine or coastal issues. Overall the field is still young, and methods of best practice are yet to be developed across all applications.

Updates

The overarching principles and techniques of user operation would require little alteration through time, but the guidelines informing users of the governing legislation would need to be reviewed regularly and updated as necessary to reflect any changes to the Civil Aviation Safety Authority (CASA) legislation on unmanned aircraft (CASA 96/17), as well as specific vessel requirements (e.g. the Marine National Facility require a protocol and qualified user). New sensors are continuously being developed so a review approximately every two years could provide updates on the applications and associated techniques as well as new technology would be required to ensure ongoing best practice methodology.

Working Group

Due to the many applications of drones to marine monitoring, any working group would benefit from being interdisciplinary with experts from government, academia, and industry with experience in various applications of drone data from acquisition to data management. It is highly feasible to establish a working group to develop content for a drone SOP, as there is already an engaged community of drone users in Australia. Due to suggested work for dugong and shark monitoring using drones, the AIMS and CSIRO should also be engaged.

Potential scope of SOP

The scope of this SOP would be limited to drones under 25 kg because these either do not require an operator licence (< 2 kg) or can be operated in Australia with a Remote Pilots Licence (2-25 kg). Successful flight operation underpins all quality drone-based data acquisition, as such, it is important that the SOP should incorporate and build on the logistical and operational guidelines presented by Joyce et al. (2018). The greatest utility of the SOP would be derived from additional sections providing guidance on the integration and operation of different sensors with drone systems. This would ensure users had a central point of reference that delivered the methods of best-practice for the different applications of drones. Special care should also be taken to detail the legal considerations that fall upon the operation of drones.

Assessment and recommendation

A set of SOPs for drones is important to streamline adoption and application across the various disciplines that stand to benefit from high-resolution remote imagery, and to ensure that data are collected and processed consistently to allow for meta-analysis. With rapidly evolving technological capabilities such miniaturisation of sensors for drones, as well as future advances in swarm theory (Allan et al. 2018), the assessment and development of SOPs is timely and would constitute a high-value addition to best practice marine research in Australia and internationally.

2.6 Satellite imagery

Earth observation from satellites has revolutionized our view of the oceans and offers vast potential for marine monitoring. Optical sensors such as Sea Surface Temperature and Ocean Colour sensors rely on the sun as the sole source of illumination and are therefore considered passive sensors. Active sensors such as radars and lidars, on the other hand, detect reflected responses from irradiated objects. The most common and useful relevant parameters for marine monitoring are sea surface temperature, chlorophyll *a* (Chl *a*) and Chl *a*-derived primary production, sea surface height, sea surface salinity, waves and windspeed.

Existing SOPS & applications to marine monitoring

The applications of satellite remote sensing in marine monitoring are extremely varied and include coastal and off-shore applications.

In shallow water environments, satellite remote sensing has been extensively used for estuarine and coastal habitat mapping and marine spatial planning. Habitats mapped include seagrass meadows, kelp forests, coral reefs, wetlands and mudflats (reviewed in Kachelriess et al. 2014; de Araujo Barbosa et al. 2015; Ouellette & Getinet 2016). Satellite remote sensing data has also been successfully integrated into coastal ecosystem risk assessments (reviewed in Murrey et al. 2018). Satellite imagery is now also an integral part of coral reef monitoring and early detection of bleaching events (reviewed in Hedley et al. 2016; Pearce and Feng 2013; Huang et al. 2018; Bajjouk et al. 2019), and it is even being used to detect individual marine animals especially whales and birds on ice.

In offshore environments, satellite remote sensing data has been used to define pelagic bioregions and describe dynamic oceanographic features such as fronts, eddies and regional upwellings, which have been associated with increased biological activity (reviewed in Kachelriess et al. 2014). In addition, satellite remote sensing has assisted in the monitoring of anthropogenic threats and pressures including global climate change (Foster et al 2014, Fundstan et al 2018, reviewed in Behrenfeld et al. 2006 and Yang et al. 2013), oil spills (reviewed in Brekke and Solberg 2005), vessel detection (reviewed in Crisp 2004) and fisheries stock assessments (reviewed in Klemas 2013).

In the early 2000s, NASA commissioned the development of a series of ocean optical measurement protocols (Mueller et al. 2003) which have promoted the collection and assembly of climate quality, ocean optical datasets by the global ocean colour community. There have since been major advances in instrumentation and observing capability, so these community-vetted protocols are now being revised to account for new, emerging, and planned capabilities and modes of deployment through the International Ocean Colour Coordinating Group's *Ocean Optics and Biogeochemistry Protocols for Satellite Ocean Colour Sensor Validation* series. These newly drafted protocols are being made available to the international user community for a period of time for testing, public comment and review, before they are accepted as international reference standards (Neeley and Mannino 2018).

Due to the complex and ever-evolving nature of satellite sensors and their applications, no recent SOPs have been developed to standardise data analyses and interpretation. However, remote sensing data for many oceanographic variables are now available as standard products.

Updates

The field of satellite remote sensing with its varied applications and developments in image processing techniques is extensive and fast-paced. There are constantly new algorithms and models being developed to calibrate and process imagery data for specific purposes. Regular updates and revisions would therefore be crucial in order for any remote sensing SOP to stay relevant, with updates being considered every year.

Working Group

The International Ocean Colour Coordinating Group (IOCCG) is the primary group linking research organisations, satellite providers and government agencies working in ocean colour and marine remote sensing. The IOCCG facilitate a number of working groups across a range marine remote sensing applications, along with publication of key reports documenting the state of the art and recommended procedures for various disciplines and application fields (http://ioccg.org/what-we-do/ioccg-publications/ioccg-reports/). Within Australia, there is no formally established working group covering marine remote sensing, although coordination and collaboration between academia and government is often established under the IMOS remote sensing facility to establish standard practises, validation and calibration such as the recent IMOS Radiometry Task Team. (http://imos.org.au/facilities/task-teams/radiometry/).

Potential scope of SOP

SOPs for satellite imagery should focus on a specific sensor or application. It would most likely include a comparison of physics-based and empirical algorithms in order to compare the resulting data and assess the SOPs broader applicability.

Remote sensing data products are classified according to their processing level from raw to end-user data, and a given SOP can encompass the full range of these:

- Level 0 and Level 1 data comprise raw data plus ancillary data, which require specialised centres for processing.
- Level 2 data include geolocation and atmospheric corrections and for many scientific users, this is the first exploitable data level. Also included in this level are derived

geophysical variables such as chl-*a* concentration and sea surface temperature (SST).
- Level 3 data are derived geophysical variables that have been aggregated/projected onto a well-defined spatial grid over a well-defined time period.
- Level 4 includes derived products that require parameters and model applications not necessarily extracted from satellite remote sensing (e.g. primary production, composite SST) (Chassot et al. 2011). To use the most relevant remote sensing product the spatial, temporal and spectral resolution of each product must be considered. In addition, the intrinsic nature of the physical models and empirical algorithms leads to uncertainties and inconsistencies in the resulting environmental variables, which must be considered in any application.

Assessment and recommendation

Due to the diversity of satellite remote sensors that are currently in operation and the specific application of each sensor for marine monitoring developing an SOP for standardised processing of satellite imagery not only seems unfeasible but also of limited use. However, there is the potential for a SOP(s) to be developed for specific sensors or monitoring applications, which should follow international best practices as outlined by the IOCCG and building on current marine remote sensing initiatives such as the *Feasibility Study for an Aquatic Ecosystem Earth Observation System*. In addition, perhaps through forums such as the annual AMSA conference a marine remote sensing group could be established to better coordinate the development of standardised approaches with an Australian focus.

Alternatively, there is also a need for guidance on which products to use for particular applications (or which ones not to use). There are multiple similar products available, each with slight differences and limitations that could be clearly articulated as a foundation to SOPs. Although not exactly an SOP, this guide could also include a regularly updated overview of all sensors and available datasets including spatial, temporal and spectral resolutions.

3. SAMPLING TARGET

3.1 Marine plastics

Marine plastics sampling and analyses is becoming increasingly common, and national protocols will ensure that data collected can be compared and collated among different surveys and different times.

Existing SOPS & applications to marine monitoring

There are a number of several established SOPs for assessing marine plastics, encompassing a range of plastic size (microplastics to large marine debris) and habitats (open ocean to sediments). These are currently being summarized into single document as part of a Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) working group. Globally, this working group aims to achieve harmonisation among approaches. Their Terms of Reference state that they aim "to develop guidelines covering terminology and methodologies for the sampling and analysis of marine macro-plastics and microplastics". In addition, CSIRO also has handbook which includes survey methods for plastics at sea, as well as on land (rivers, inland, coast) (Schuyler et al. 2018).

Certain methods for sampling marine debris can be applied to marine monitoring (i.e. change detection), including that done by plankton collection, drones, ship intake waters or visual surveys.

Updates

Marine plastics is currently a dynamic and high-profile topic. As such, updates may be required every year, with 2-5 years suggested for synoptic reviews to ensure linkages with emerging technologies and methodologies.

Working group

With the existence of the GESAMP working group, any new initiative should either leverage off this group or develop an Australian node.

Potential scope of SOP

A given SOP must specify the particle origin (suspended, sinking, ingested, deposited on the seafloor) and size class (macroplastics to nanoplastics), as well as the variable to be measured (distribution, polymer type, size, shape). The scope will depend on the marine monitoring objectives and region. The GESAMP report outlines all of these methods.

Assessment and recommendation

We suggest taking advantage of new work coming out in this space and holding off on the development of any new SOPs until the results of the GESAMP report are available. This report is currently in revision stages and has input from international experts in the field. In the meantime, Schuyler et al. (2018) can be used to ensure nationally consistent methods.

3.2 Environmental DNA (E-DNA)

Fragments of species-specific environmental DNA (eDNA) can be analysed from seawater and sediment to assess community composition across all domains of life and to provide an indication of an organism's past or current presence.

Existing SOPS & applications to marine monitoring

eDNA has been used to develop species inventories (Brown et al. 2018), identify rare or invasive species (Rees et al. 2014) and even detect different populations (Sigsgaard et al. 2016). Metabarcoding of eDNA is often quicker and more sensitive than traditional sampling (Boussarie et al. 2018), although its application to environments in which the fauna are poorly known is limited (e.g. deep-sea platyhelminthes and nematodes in Sinniger et al. 2016). Although there have been numerous efforts to apply eDNA to abundance and biomass estimation (e.g. Pilliod et al. 2014, Klymus et al. 2015), these parameters have yet to be proven as a reliable measurement from eDNA. Current approaches employ different eDNA methods among different environments (eg pelagic vs. benthic), but there is a move to develop standardised methods so that data can be compared among different surveys (Djurhuus et al. 2017).

For the pelagic environment, there is a broadly used existing SOP for microbial genomics (https://data.bioplatforms.com/organization/pages/australian-microbiome/methods). For the metazoans and benthic biota, there are several approaches for sampling based on environmental characteristics. For example, sediment samples are often collected by divers in <30m waters, while deep sea sediments are typically collected by sophisticated coring devices (Przeslawski et al. 2018).

Updates

Any manual for eDNA work should be assessed for updates every two years, with likely updates needed every 5 years. eDNA methodologies are rapidly evolving, particularly for metazoans.

Working group

There are several groups working on pelagic and benthic marine genomics, with specific interests in microbiology, sediment infauna and pelagic macrobiota. Many of these groups are already connected, for example, through the CSIRO-led eDNA Community of Practise workshop held in early 2018. There is strong potential for a formal working group if support is provided, and further options may be explored through developing projects and infrastructure (e.g. Environomics project of CSIRO Future Sciences Platform).

Potential scope of SOP

Methodologies for microbial eDNA work are fairly well established, with standardisation in place for many large studies. Methodologies for macrobial eDNA work, on the other hand, is in the stage of rapid evolution, and require a SOP. There is a strong case to develop national SOPs for sample collection and processing for eDNA – one for pelagic (water) samples and for benthic (sediment) samples.

Assessment and recommendation

There is a need for a pelagic SOP and a benthic SOP that focus on metazoan sampling and analysis. Collecting samples, especially those embedded in contextual observations, is the most expensive part of eDNA work. A single sample provides enough DNA for a range of different genomic analyses. Standardising sample collection and processing across different projects, and spatial and temporal scales, can exponentially increase the impact of these projects.

However, before an SOP is developed, different sampling methods should be compared. The study needs to analyse the effects of variations in protocols, in particular of sample size and filter size, on the observed presence and diversity data across all domains of life. Such a project has been initiated for pelagic sampling through the Australian Microbiome program, but it has yet to be undertaken for benthic sampling. Results of such studies will provide the framework to agree on a standardised approach.

National standards for both pelagic and sediment sampling for eDNA should be driven by practical considerations, costs, logistics, and limiting the labour required per sample, thus enabling a broad roll-out of eDNA sampling to marine and estuarine field campaigns.

3.3 Plankton

Plankton (phytoplankton and zooplankton) are an integral component of the marine environment, and researchers have adopted many methods to best sample for plankton. There are many platforms for sampling plankton including various style nets and traps. With best practice techniques, sampling plankton can be used to monitor changes in species assemblages, abundance, water quality and oceanography (Suthers and Rissik 2009).

Existing SOPS & applications to marine monitoring

There is no national SOP for sampling plankton, although many institutions may have their own internal SOPs. Often researchers focus on one aspect of the plankton, either fish larvae, zooplankton or phytoplankton, and therefore adapt methods that best suit their need. Many researchers follow the methods outlined in historical papers to allow for comparisons. There is a significant amount of peer-reviewed literature that outlines and compares the different methods used. It would be worthwhile do a desktop study to establish the most common methods that work in oceanographic conditions, particularly when working past the outer-shelf region in >100 m depth.

A new book, due to be released in early 2019 titled *Plankton: Guide to their ecology and monitoring for water quality, second edition* by Suthers et al. is an expansion on Suthers (2009). This book outlines best practice methods for sampling, storing and sorting plankton and would make a good starting point to develop a national SOP. There is still need for an SOP to provide clear, concise and collaborative methods that can be applied by researchers in the field.

There are currently programs and initiatives aimed at standardizing sampling and data for nationwide monitoring of certain aspects of the plankton assemblage. These efforts have international ramifications due to the abundance and biomass of both phytoplankton and zooplankton being identified as Essential Ocean Variables. Most notably, the National Ichthyoplankton Monitoring and Observing (NIMO), which is incorporated into the Integrated Marine Observing System (IMOS), has recently been established (Smith et al. 2018). This initiative aims to compile data collected around Australia from particular sites with the same methods to collect and quantify samples of fish larvae. A phytoplankton database also exists within the AODN framework, storing over 3.5 million data records (Davies et al. 2016). The Continuous Plankton Recorder (CPR) offers a platform-specific method of sampling plankton while underway and has its own SOPs that should be referred to or integrated into other SOPs as needed.

Updates

Sampling for plankton is a well-established practice, although there have been recent developments in automated image analysis and sensors (Ohman et al. 2019), as well as progress made to harvest more information from the CPR (e.g. genetics, electron microscopy). With a good working group, SOPs will thus require updates mostly to post-processing steps. The majority of updates will likely occur with the first one to two years as the agreed methodology is refined.

Working group

There is has already been interest in forming a working group to develop an SOP for sampling plankton in Australian waters, as a concise and field-appropriate resource based on Suthers et al. Researchers working in the field plankton research are already well-connected and would be willing to contribute time if support for such a project could be provided.

Potential scope of SOP

Several surveys in Australian waters on the national research vessel (*RV Investigator*) have a plankton sampling component. These surveys could be used as a foundation for the working group to refine the scope of a national SOP, namely defining the target taxa (including size), tow characteristics, and sample and data processing.

Assessment and recommendation

We suggest taking advantage of an offer from experts in the field of plankton sampling to develop an Australian SOP for sampling plankton. This would most likely be in the form of a one-day workshop to table existing methodology and establish a standardised method for sampling, storing and sorting plankton collected in Australian waters. This will be a challenging task as there are so many various methods used for sampling certain aspects of the plankton assemblage. Any SOP would need to ensure it encompassed each aspect (or be separated into discrete SOPs).

4. CULTURAL

4.1 Sampling for Sea Country

The desire for knowledge transfer and the integration of modern science approaches to monitoring marine communities in developing regions has long been recognised. For example the Survey Manual for Tropical Marine Resources (English et al. 1997), was developed as part of the ASEAN-Australia Marine Science Project to assist developing nations to monitor coastal resources. This manual provided a range of “SOPs” focussed on the adoption of standardised approaches to data collection and storage to promote national and international collaboration in monitoring coral reefs, mangroves, seagrass, soft-bottom communities and coastal fisheries, but was targeted predominantly at emerging scientists in developing nations, rather than Indigenous communities.

Existing SOPS & applications to marine monitoring

Building on this concept and in response to the desire of Australia’s Indigenous coastal communities to develop deeper relationships with marine scientists and build self-determination through monitoring their own Sea Country, AIMS commenced the development of an Indigenous SOPs (ISOPs) manual in 2016 (Depczynski et al. in preparation). The ISOPs are unique in acknowledging and incorporating Traditional Ecological Knowledge (TEK) into the marine monitoring philosophy. This is captured through the joint-development of individual SOPs monitoring methods and a participatory mapping process which underwrites the sampling designs for monitoring of Sea Country for each individual community. Together, this process of combining TEK with western science provides a culturally appropriate and powerful means of documenting and monitoring the health of marine ecosystems that is based on partnership and equality.

To date, ISOPs have been developed for monitoring fish (using simplified BRUVS), benthos (using a drop camera system), water quality and sediment. The draft ISOPs were developed initially in conjunction with the Anindilyakwa (Groote Island) and are currently being tested with other Indigenous groups in Northern Australia in order to understand appropriate delivery, uptake and to refine accordingly. Testing of ISOPs is also capturing “transferability” across different local cultures; for example recognising that species of cultural significance vary among regional groups and hence different monitoring tools/approaches may need to be developed.

In parallel, the WAMSI Kimberley Indigenous Saltwater Science Project (KISSP) undertook the development of the Kimberley Saltwater Monitoring Toolbox (Dobbs et al. 2017), which provides a framework for developing Indigenous monitoring, incorporating identification of values, threats, prioritisation and monitoring. The Toolbox also provides summaries of monitoring methods already being implemented by Kimberley Indigenous groups that could be considered in developing future SOPs. An Introduction to Monitoring for Management (Lincoln et al. 2017) was also developed as part of KISSP which provides a pilot learning package for Indigenous Rangers to help them build a conceptual knowledge of monitoring. A similar initiative was developed with turtle and dugong monitoring through the NERP Northern Australia Hub and North Australian Indigenous Land and Sea Management Alliance (NAILSMA). In this program, a boat-based survey approach was applied by Indigenous rangers to monitor cultural values (e.g. turtles and dugongs), ultimately applying a collaborative partnership model that supports Traditional Owner aspirations and conservation objectives (Jackson et al. 2015). More broadly, NAILSMA supports the Indigenous Tracker (I-Tracker) program, a suite of digital applications used to collect and share data for a wide range of natural and cultural resources, including Sea Country (nailsma.org.au/projects/i-tracker).

Updates

Once developed, SOPs are unlikely to need regular updates and should be assessed approximately every five years.

Working group

The work undertaken by AIMS, KISSP and others has shown the interest in, and value of, Indigenous Marine Monitoring, and ISOPs will be an integral part of this to ensure better geographical coverage and comparability of data to form a national perspective of marine ecosystem health.

Potential scope of SOP

ISOPs have already been developed at a regional or local scale for monitoring species of cultural significance (Kennett et al. 2010, NAILSMA 2014) including marine mammals (Jackson et al. 2015), turtles (Jackson et al. 2015), seagrass (Howley et al.) and mangroves (Hub 2017), and could provide foundations for developing national scale ISOPs. There are currently no ISOPs for monitoring for environmental perturbations such as coral bleaching, oil spill response, invasive species detection, marine debris and microplastics and other specific environmental impacts. However, uptake of ISOPs will be contingent on a structured program of training and knowledge development/understanding and may also need to be supported (at least initially) i.e. through data analysis and interpretation by the scientific community. In this context, the resources required for development and roll-out of additional ISOPs are likely to be high, but they can certainly build on the existing frameworks already developed through AIMS, KISSP, and NAILSMA.

Assessment and recommendation

The incorporation of traditional knowledge into marine management, and particularly the collaboration between Traditional Owners and western science in monitoring Sea Country has recognised social, economic and environmental value. Western science institutions will benefit through nationally consistent and comparable datasets, while Indigenous communities will benefit by empowerment to manage their own country in a culturally appropriate manner.

We recommend continued development of ISOPs through existing programs to facilitate engagement with Traditional Owners, empower Sea Ranger groups to scientifically manage their own Sea Country using a culturally appropriate framework and provide considerable baseline and monitoring data to inform management of ecosystem health nationally. However, unlike standard scientific SOPs we cannot just print manuals and expect Traditional Owners to use them. Adoption of ISOPs requires considerable engagement, education and collaboration, with full implementation likely to be a longer-term (and resource-intensive) goal.

5. SOCIOECONOMIC

5.1 Socioeconomic monitoring of marine parks

Existing SOPS & applications to marine monitoring

Social and economic monitoring has accompanied the implementation of some previous Australian Marine Parks (AMPs), and these methods will be incorporated into our SOP where possible. Incorporating previously used methods allows our proposed SOP to leverage off previous experience of social and economic monitoring. . Adopting previously used metrics also provides a sense of continuity and familiarity with previous approaches, whilst being integrated into a contemporary and comprehensive approach.

Social and economic values are key drivers for marine science and marine policy but are too rarely integrated with marine biodiversity monitoring programs. This makes marine spatial planning and cross-sectoral decision-making challenging. Parks Australia (PA) are currently considering options for developing social and economic baselines, which will be in large part informed by development of a Monitoring, Evaluation, Reporting and Improvement (MERI) framework to capture and monitor social and economic values. With management plans recently coming into effect (July 2018) for 44 of the Australian Marine Parks, PA are keen to identify and capture key social and economic metrics as soon as possible, while still considering existing work and being part of a nationally consistent approach where possible. We are at an ideal stage to engage with PA and other management agencies to provide scientific input to develop theoretically rigorous frameworks that can be applicable nationally to capture social and economic values associated with Marine Parks.

Updates

Whilst methods for social and economic assessment are not prone to rapid change, shifts in the information needs of policy makers are likely to change over time. To be effective therefore a SOP for the evaluation of social and economic values should change to meet these needs. Minor review of SOP for social and economic assessment may be needed every 5 years, or if the needs of policy makers are perceived to have changed drastically.

Working group

PA and various state agencies relevant to Marine Park policies have shown keen interest in enhancing methods of social and economic assessment in recent years. A major barrier in doing so has been the absence of clear guidelines on best-practices. We believe that all parties would stand to gain from participating in a working group to develop content for a SOP, and therefore perceive a strong likelihood of participation. Key participants should include fisheries and park management agencies, as well as universities and state and Commonwealth agencies.

Potential scope of SOP

Different Marine Park stakeholders require different engagement and data collections processes (recreational fishers, commercial fishers, non-fishing recreational users, fishing and non-fishing tourism operations, petrochemical and mineral industries and the general public). These agencies should be involved in the co-development of rigorous frameworks and SOPs to establish robust methodologies that capture the social and economic metrics relevant to AMPs. As part of this process, the number and scope of required SOPs will be identified.

Assessment and recommendation

Monitoring of Social and Economic values derived from Marine Parks is clearly required to understand and improve upon the performance of AMPs. There are multiple advantages to integrating social and economic assessment into a SOP. First, previous approaches to social and economic monitoring have varied significantly between agencies, and best-practices are often difficult to identify. This problem has been compounded by a shortage of dedicated social and economic trained staff in state and federal agencies. The result has been mixed reporting methods, and no clear understanding of the implications for policy of findings from social and economic monitoring.

By contrast a national standardised approach would maximise policy relevance and interpretability of results and allow the identification of opportunities for cost-effective, national-scale collaborations that foster a standards-based approach to collecting social and economic values data and information. We recommend the first stages of this be implemented through the NESP Marine Hub, as resources are available in 2019-2020 to develop a project-specific SOP from which further extensive collaboration and review could result in a national SOP (i.e. field manual).

6. RECOMMENDATIONS AND CONCLUSIONS

This report has scoped SOPs related to marine sampling, including those based on sampling target, sampling platform, and socioeconomic and cultural aspects. Recommendations from each section are summarised in Table 2.

Table 2: Field manuals scoped in the current report, with associated summary recommendations. Potential sources of support are also listed, noting that these agencies have not agreed to do so and are simply known to have an interest in the topic.

Potential New Field Manual	Recommendation	Potential Sources of Support[1,2]
Sampling Platforms		
Underwater visual census	Review current SOPs, and work with key users to develop a national standard that integrates current methods (or a 'rosetta stone' that maps between methods)	NESP Marine Hub, IMOS, AIMS, UTAS
Remote operating vehicle	Include a new ROV chapter in the *Field Manuals for Marine Sampling in Australian Waters* in 2019-20.	NESP Project D2, UTAS
Passive acoustics	Review current SOPs, and adapt these to develop a national standard including standards for calibration and units	Oil and gas industry, NOPSEMA, IMOS, Curtin, DSTO
Sub-bottom profiling	Develop an SOP and cross-reference and cross-promote with the *Field Manuals for Marine Sampling in Australian Waters*	AusSeabed, GA
Drones	Review current SOPs, and adapt these to develop a national standard	State governments, Digital Earth Australia
Satellite Imagery	Develop a regularly updated guide reviewing current data products, potential applications and limitations	Digital Earth Australia, CSIRO, agriculture industry, IMOS

[1] Includes direct funding and in-kind contribution

[2] NESP – National Environmental Science Program, IMOS – Integrated Marine Observing System, AIMS – Australian Institute of Marine Science, NOPSEMA – National Offshore Petroleum Safety and Environment Management Authority, GA – Geoscience Australia, UWA – University of Western Australia, AAD – Australian Antarctic Division, DSTO – Defence Science and Technology Organisation

Sampling Target		
Marine plastics	Postpone development of any new SOPs until the results of the GESAMP report are available.	n/a
e-DNA	Undertake an initial study comparing different sampling methods to then inform national standards for pelagic and sediment sampling for eDNA.	CSIRO, NESP Marine Hub, universities
Plankton	Accept offer from experts in the field to develop an Australian SOP for sampling plankton.	CSIRO, AAD, NESP Marine Hub, universities, fisheries groups
Cultural		
Sampling for Sea Country (i.e. abridged field manuals)	Support the development of ISOPs already being developed, including associated engagement, education and collaboration, noting full implementation is a longer-term (and resource-intensive) goal.	AIMS, NESP Northern Hub
Socioeconomic		
Socioeconomic monitoring	Pursue first steps of potential SOP as part of NESP Project D6 in 2019-2020.	NESP Project D6, UWA

Based on different aspects considered here, one field manual seems necessary and achievable for the NESP Marine Hub program in 2019-2020: An ROV field manual was identified by various collaborators and potential users as an obvious omission in the original suite of field manuals. This platform is burgeoning in its use, and now is the right time to develop an SOP for it, lest multiple approaches are developed and followed. In addition, and fortuitously, we have the expertise available in the existing NESP Project D2 team to lead and contribute to a new ROV manual. This field manual would be of broad use to the marine community, and its development is practical due to the willingness of a strong community of experts to contribute.

In addition, the development of a project-specific SOP on socioeconomic monitoring should be progressed in 2019-2020 as part of the new NESP Project D6. The release of an associated field manual will not occur until later, due to the extensive collaboration and review required to be considered a national SOP. Nonetheless, this new project is well-placed to form a working group and start to develop content.

A further six SOPs and associated field manuals may be developed in the future (UVC, PAM, SBP, drones, e-DNA, plankton). This assumes suitable resources are secured, including a champion to chair a working group and lead the field manual. If the same collaborative process as described in the original suite of field manuals (Foster & Przeslawski 2018) is applied, any new field manuals can be ensconced in new versions of *Field Manuals for Marine Sampling to Monitor Australia's Waters.* This would allow the SOPs to benefit from the extensive promotion and outreach already undertaken via NESP Project D2. In contrast, some of these field manuals may be managed by programs other than NESP. In particular, an SOP on sub-bottom profiling seems a better fit for AusSeabed due to that program's focus on seabed mapping and geophysics.

The process to develop the original suite of field manuals had a particular emphasis on an open and collaborative approach. Such an approach should also be applied with any future field manuals.

Recommendations from this report indicate that three of the scoped SOPs are not needed in the near future, either due to broad scope precluding a national SOP (satellite imagery, although we do recommend that some guidance be developed on appropriate data sets to be used), or other initiatives that are already in advanced development stages (marine plastics, sampling for Sea Country). From the perspective of the NESP Marine Biodiversity Hub, support for these latter two projects may be considered in the future if further development is required, particularly related to marine monitoring applications.

Regardless of which program or agency leads or authors a SOP, the product and underlying development process should be readily accessible. The Ocean Best Practice Repository (www.oceanbestpractices.net) is one such platform to store and search SOPs, guidelines, and best practices from around the world. By ensuring that the SOPs collaboratively developed in Australia are on such a repository, the rate of international uptake may be increased. Such platforms can also highlight how SOPs and open data may form part of the backbone of a global system to manage marine data.

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